Electric Feedback Forum
Office of Governor Martin O'Malley
Improving Maryland's Electric Distribution System

Roundtable Discussion #4: What investments should customers be encouraged to make (or not to make) to increase their reliability?

August 28, 2012, 1:30pm – 4:30pm
President's Conference Room East 1 and 2
Miller Senate Office Building
11 Bladen Street
Annapolis MD, 21401

Executive Order 01.01.2012.15

List of Invited Participants

Rajnish Barua, Ph.D., Executive Director, *NRRI*

Dr. Eric Wachsman, *University of Maryland*

Mary Lasky, Business Continuity, *Johns Hopkins Applied Physics Lab*

Chris Cook, President and General Counsel, *Solar Grid Storage, LLC*

Dr. Ben Hobbs, *Johns Hopkins University*

Dr. Danny Ervin, *Salisbury University*

Tom Glennon, *Honeywell*

Are Smart Microgrids in Your Future? Exploring Issues and Challenges for State Public Utility Regulators

Based on a forthcoming NRRI research paper by
Tom Stanton, Principal Researcher, NRRI

Note: The final paper may not exactly reflect issues raised and comments made in this preliminary presentation.

Two basic visions for microgrids

- Autonomous but interconnected, integrated, local, self-stabilizing distributed energy systems including:
  - loads and load management, demands and demand response;
  - distributed generation with district heating & cooling;
  - distributed energy storage (electric & thermal); and
  - with intentional islanding when cost-effective and during macrogrid emergencies.
- Autonomous, non-interconnected, remote distribution-scale energy networks

Why should we care about microgrids?

- A declining-cost, least-cost, high efficiency, high reliability, enhanced security approach that can serve many customers
- An option that can defer or prevent spending on avoidable, strandable alternatives in traditional generation, transmission, and distribution infrastructure
- High power quality, high-reliability service for especially sensitive loads
- Reduced energy waste and reduced negative environmental impacts

Major obstacles and barriers for PUCs

- Policy uncertainty – Are microgrids allowed?
  - Can consumers exchange electricity or thermal energy? If yes, which consumers and with whom?
  - Individual consumers can self-generate, but can groups of customers co-invest, to take advantage of economies of scale in distributed generation (and storage) resources and load diversity?
- Prevention of intentional islanding – Are microgrids allowed to continue service during macrogrid outages?
- Need to update interconnection rules and procedures based on new IEEE standards?
- Regulatory incentives do not always reward utilities for the most efficient investments and operations

Major non-PUC obstacles and barriers

- New technologies with little if any track record proving safety, reliability
- Siting and zoning challenges
- New IEEE 1547.4 intentional islanding standard
- Are tax policies fair to both central station and distributed resources? – property taxes, income taxes, depreciation?
- Higher-cost financing and less access to capital for distributed resources and related innovative technologies

Possible business models for utility-sponsored microgrids

- IRP-driven decisions selecting least-cost, highest reliability, most secure energy infrastructure
- Utility performance incentives for power quality and reliability, with rates decoupled to remove the utility's throughput incentive
- Utility ROI for distributed resources, including smart microgrid controls

Possible business models for Distributed Resources

- Whether utility-, customer-, or third-party owned and operated:
  - Fair compensation for distributed resources, including energy, capacity, and ancillary services produced and delivered
  - All distributed energy production either used on-site or interchanged under net metering rules or as wholesale transactions at full avoided cost

Start with critical energy infrastructure, and work outwards from there

- Utilities can gradually segment the grid into zones eligible for microgrid operations
  – Hospitals, emergency shelters, first-responder facilities
  – Customers needing – and willing to pay for – ultra-high reliability
  – Single-customers with diverse loads (campuses of all kinds)
  – Physical islands and remote loads
  – Tie into state brownfield redevelopment incentives?

Near-term, first-step policies

- Identify one or more microgrid “enterprise zones” and develop operations there, on an experimental or pilot basis
- Inventory current laws, rules, and regulations to identify existing barriers and obstacles
- Develop at least provisional, model regulations for microgrids
- Support development and implementation of smart-grid interoperability standards

Longer-term policies

- Clear a regulatory path to allow microgrid development
- Establish rules, regulations, and bi-directional tariffs for the exchange of electricity and thermal energy among groups of unrelated customers (either peer-to-peer or through a wholesale market)

Fuel Cells for Reliable Baseload Power, from Residential Scale to Microgrid

Eric D. Wachsman, Director

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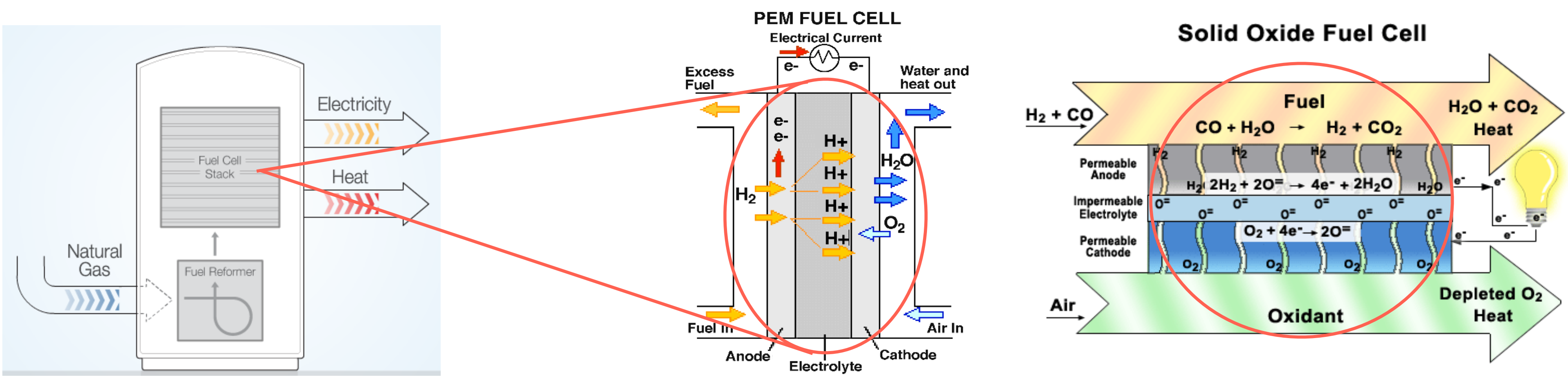
UNIVERSITY OF MARYLAND

Energy Research Center

Fuel Cell Technologies

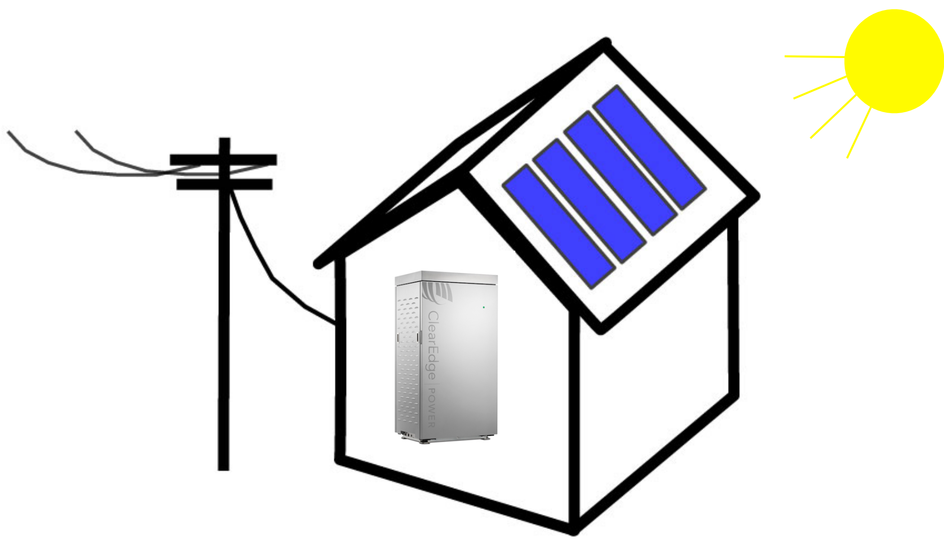
- Fuel cells are available to provide residential (~5kW) through multi-MW distributed generation (DG)

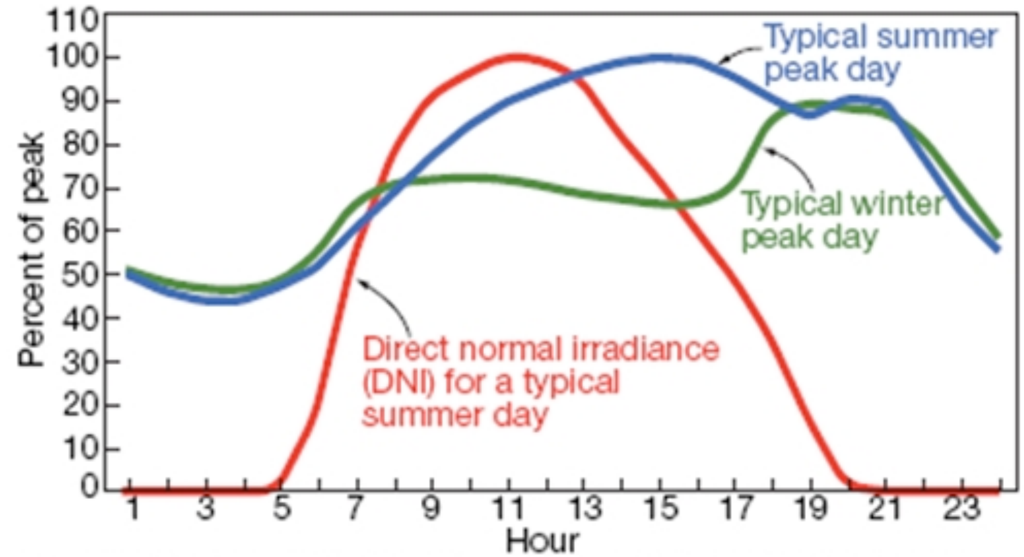
- Fuel Cells electrochemically convert fuel and air to electricity with high efficiency
  - up to 60% for electric power generation
  - up to 90% for combined heat and power (CHP)



- Operate on a variety of fuels (e.g., natural gas and biogas) with fuel reformer
- Provide baseload (24/7) power with reduced CO_2 emissions
- Increase grid reliability

Enable Solar PV Generation





24. Solar power produced at maximum DNI is stored in a battery and released later in the day when demand is highest

- Only works when sun shines
  - Low capacity factor and energy produced (kWh) per rated power (kW)
- Interconnect shuts system down when grid goes down
  - Does not provide backup/emergency power
- Battery storage shifts peak but doubles system cost without generating any more power
- Genset can provide baseload but with low efficiency and high emissions, noise and maintenance
- Fuel cells can generate the necessary baseload power to enable solar PV generation with high efficiency, and negligible emissions, noise and maintenance

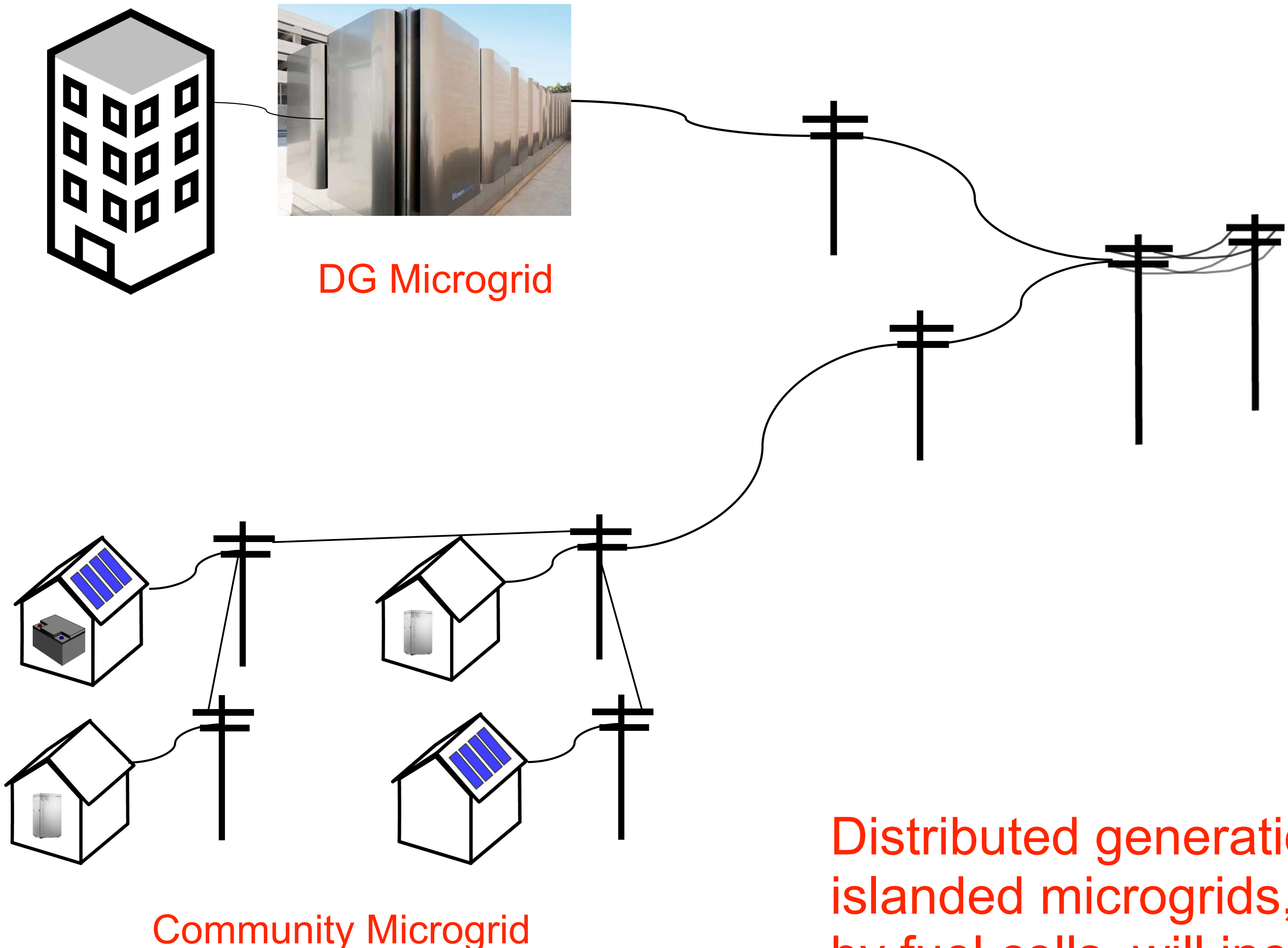
Comparison of Technologies

Comparison of features/costs for residential and distributed generation systems

	Residential 5 kW System			1.5MW DG
	Photovoltaic	Generator	Fuel Cell	Fuel Cell
Fuel consumption	0	High	Low	Low
CO_2 emissions	0	High	Low	Low
CO/NO_x emissions	0	High	Negligible	Negligible
Noise	None	Loud	Quiet	Quiet
Maintenance	Negligible	High	Negligible	Negligible
Lifetime for 24hr/day operation	~20yrs	<1yr[1]	>10yrs	~20yrs
Installed system cost[2]	$20K	~$10K	~$50K	~$3.6M
Peak power availability/day	<2hr	24hr	24hr	24hr
Annual power production	~5,200kWh[3]	43,800kWh	43,800kWh	13,140MWh
Capital cost over lifetime	~$0.19/kWh	>$0.23/kWh	<$0.11/kWh	~$0.01/kWh
Fuel cost at retail NG cost[4]	0	~$0.09/kWh	~$0.04/kWh	~$0.04/kWh
Levelized cost of electricity[5]	~$0.19/kWh	>$0.32/kWh	<$0.15/kWh	~$0.05/kWh

[1]Typical air- and water-cooled gensets run for ~500 hrs and ~8000 hrs, respectively, between rebuilds. They are not designed to run continuously and are for emergency backup power only.
[2]With no rebates or tax credits.
[3]Based on annual average solar insolation for Baltimore.
[4]Current retail natural gas cost is $0.55/therm. Assumes fuel cell and genset efficiencies of 50% and 20%, respectively. Does not take into consideration higher efficiency fuel cell CHP systems.
[5]LCOE does not include financing charges.

Enable Islanded Microgrids



Distributed generation and islanded microgrids, enabled by fuel cells, will increase grid reliability and resiliency

Recommendations

- Provide the same financial incentives (rebates) for fuel cells as for solar and geothermal
- Remove net metering limitation that reduces credit from retail rate to commodity energy supply rate when annual generation exceeds annual consumption
- Since fuel cells are a growing industry, target DBED resources and innovation funding to grow that industry in Maryland
- Develop codes/regulations to allow residential to community scale generation to stay on-line as islanded microgrids during outages
- Mandate utilities to provide "smart transformer" interconnect technology and grid-tied inverters integrated with smart meters as installed option for customers
- Extend natural gas pipelines while doing other infrastructure improvements

Fuel Cells for Reliable Baseload Power, from Residential Scale to Microgrid

Eric D. Wachsman
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Fuel cell systems can provide reliable uninterrupted baseload power for distributed generation (DG) applications up to scales of a few MW. They produce almost no harmful emissions with minimal noise and thus, can be sited almost anywhere. In addition, their maintenance schedules are proving to be simple and low-cost. If widely deployed, they can provide significant improvement in power reliability at residential, community, and commercial/industrial sites through incorporation in individual buildings and microgrids. As distributed power generators running on available natural gas or other fuels, they can provide improved grid efficiency through combined heat and power and also can establish redundancy for communities prone to local grid failure.

For distributed power applications, fuel cell systems are the most efficient technology to convert fuel energy to electricity. With natural gas feeds, fuel cell technologies can provide overall electric efficiencies up to 60%, similar to large (> 100 MW) central combined cycle power plants. Moreover, for combined heat and power (CHP) applications, over 90% of the fuel energy can be utilized in electricity and heating. Thus fuel cells could have a major impact on reducing both the fuel consumption and CO_2 emissions of grid generation today while simultaneously increasing grid reliability and resiliency through deployed DG.

While fuel cells have been linked to a hydrogen economy, numerous companies are in fact commercializing fuel cell power generation based on currently available fuels. Some of the available fuel cell technologies today as well as approaching commercialization are listed in Table 1.

Table 1 Comparison of some available and near commercial fuel cell power systems

	Market	Size	Cost ($/kW)	Fuel(s)
FuelCell Energy, CT	DG	1.5 MW	~$2400	NG, bio/waste gas
Bloom Energy, CA[1]	DG	200 kW	~$7000	NG & biogas
ClearEdge, OR	Residential	5 kW	~$11,000	NG
Ballard, Canada[2]	Residential & Backup	5 kW	~$2500	Hydrogen
	Residential thru DG	5kW-MW	N/A	NG[2]

[1]New expanded manufacturing in DE.
[2]NG based fuel processing and systems under development in College Park, MD.

A comparison of fuel cell performance and cost with solar photovoltaic generation and natural gas GenSets for residential applications is given in Table 2. The results indicate that fuel cells provide the lowest levelized cost of electricity (LCOE) as well as greater energy reliability and availability. Moreover, as capital costs decrease with increasing system size DG applications can already achieve grid parity (e.g., 1.5MW DG example) and provide attractive solution when power reliability and availability is at a premium.

Table 2 Comparison of features/costs for residential and distributed generation systems

	Residential 5 kW System			1.5MW DG
	Photovoltaic	Generator	Fuel Cell	Fuel Cell
Fuel consumption	0	High	Low	Low
CO_2 emissions	0	High	Low	Low
CO/NO_x emissions	0	High	Negligible	Negligible
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[5]LCOE does not include financing charges.

Maryland has the opportunity to simultaneously improve grid reliability/resiliency and become a leader in fuel cell manufacturing and deployment. As pointed out in the Fuel Cells 2000 report "State of the States: Fuel Cells in America", Maryland is considered to be one of the 5 "rising stars" due to its net metering policy, university research programs, and new fuel cell industry. The following recommendations would help make this opportunity a reality:

1. Provide the same financial incentives (rebates) for fuel cells as for solar and geothermal
2. Remove net metering limitation that reduces credit from retail rate to commodity energy supply rate when annual generation exceeds annual consumption
3. Since fuel cells are a growing industry, target DBED resources and innovation funding to grow that industry in Maryland
4. Develop codes/regulations to allow residential to community scale generation to stay on-line as islanded microgrids during outages
5. Mandate utilities to provide "smart transformer" interconnect technology and grid-tied inverters integrated with smart meter as installed option for customers
6. Extend natural gas pipelines for distributed power and expanded CHP opportunities with other infrastructure improvements

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ANALYSIS

Role of solid oxide fuel cells in a balanced energy strategy

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The 2012 Department of Energy (DOE) budget request significantly reduces fuel cell RD&D funding and would cease to support the Solid State Energy Conversion Alliance (SECA), DOE's solid oxide fuel cell (SOFC) program. This would be a grave mistake considering the US's historic dominance in fuel cell RD&D, exciting recent technological advancements in fuel cells, and clear positive market signals around the globe. In this paper we discuss DOE's energy RD&D policy, how SOFCs address every key DOE strategy, and why recent advances should make SOFCs an integral part of our energy RD&D policy. Moreover, we compare the prospects of low temperature SOFCs with the more common proton exchange membrane fuel cell (PEMFC) in the absence of a hydrogen infrastructure.

1. Introduction

Whether constrained by the world's limited hydrocarbon resources, or the need for emission reductions, the efficient production of electricity is a fundamental requirement for the modern world. SOFCs have the highest potential efficiency for the conversion of fuel to electricity. Their ability to operate on any hydrocarbon fuel, both conventional and biomass, or hydrogen, suggests they can play a critical role in both our current and future energy solutions.

The US has been leading efforts at lowering costs and increasing the performance of SOFCs through the DOE Office of Fossil Energy's SECA program. The program has shown significant progress with several SECA industry teams approaching commercialization of their resulting technology. Around the world, numerous countries have recognized the potential of SOFCs and have commenced meaningful commercialization efforts in combined heat and power (CHP) applications.

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Recent progress in lowering operating temperature and power density improvements have made SOFCs a unique energy technology platform that offers stunning potential for electrical generation in not only centralized, but distributed and even mobile applications. Lowering operating temperatures reduces manufacturing costs, vastly simplifies the integration of balance of plant (BOP) components and enables thermal cycling. Improved thermal cycling capabilities of low-temperature SOFCs (LT-SOFCs) would allow them to also play an important role in load following applications such as non-base-load electricity generation and transportation.

1.1 US energy RD&D policy

On March 14, 2011, DOE produced its first "Quadrennial Technology Review Framing Document" (Technology Review)

Broader impact

Fuel cells are the most efficient technology to convert chemical energy to electricity and thus could have a major impact on reducing fuel consumption and CO_2 emissions. Hydrogen is an energy carrier, not an energy resource. Unfortunately, fuel cells have been linked perceptually and programatically to a hydrogen economy. Moreover, the tremendous infrastructural cost of creating the hydrogen economy has relegated fuel cells to a "future technology". This perception has resulted in a drastic reduction in funding by the US Department of Energy in favor of vehicle electrification. In fact, solid oxide fuel cells (SOFCs) are fuel flexible, capable of operating on both conventional fuels (*e.g.*, natural gas and gasoline) and future alternative fuels (*e.g.*, H_2 and biofuels). The primary technical challenge for SOFCs has been high operating temperature and its impact on cost, reliability, and (for transportation applications) start-up time. Significant reductions in operating temperature have been achieved over the last decade without sacrificing power density, thus, reducing cost, improving reliability, and putting SOFCs on the path toward near term commercial viability in a number of stationary power applications. Moreover, recent increases in power density and further temperature reductions have made transportation applications feasible. Thus it seems clear that SOFCs are an important part of a balanced energy RD&D portfolio, with or without a hydrogen infrastructure.

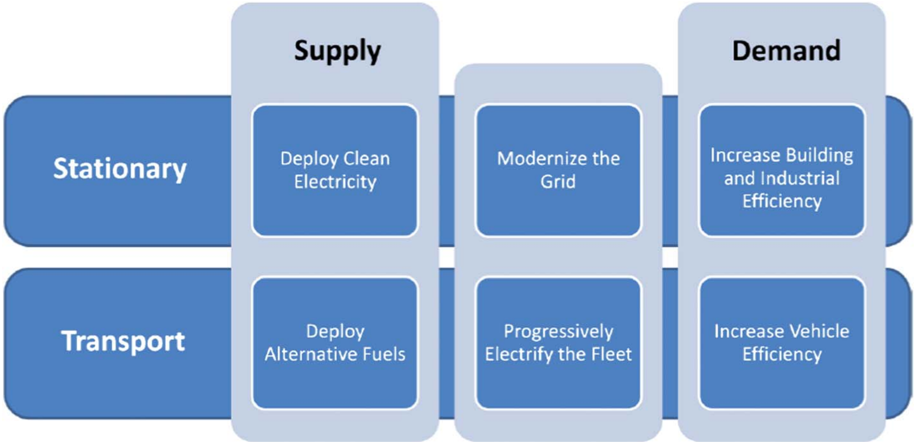

Fig. 1 Six key DOE energy strategies.[1]

as a means to facilitate stakeholder engagement in the nation's energy technology RD&D policy decisions. The Technology Review lays out six key strategies to guide efforts at achieving the Administration's high-level goals of reducing oil dependency and pollution, and creating jobs through continued investment in clean energy.[1] As shown in Fig. 1, DOE's overall plan can be viewed as a matrix of Stationary and Transportation market sectors each having a strategy that focuses on increasing energy supply, improving efficiency and beginning the strategic build-out of a new energy infrastructure. While the plan's composition appears sound, the exclusion of fuel cells from playing a meaningful role in executing these strategies does not.

As indicated in Table 1, fuel cells are singularly suited to fulfilling all of DOE's key strategies. While the other energy technologies can provide part of the solution, non-fuel cell energy technologies have characteristics that limit their applicability in one or more key strategies. For example, the primary role that wind energy can play in transportation is displacing fossil fuels in the generation of electricity (Stationary strategy) that subsequently can be used (with batteries) in an electric vehicle (EV) or plug-in hybrid electric vehicle (PHEV). While high-temperature nuclear and solar thermal can generate hydrogen for alternative fuels (Transportation strategy) or electric power for EV's, their scale limit them to large centralized generation. Similarly, batteries can be used to compensate for renewable energy's transients, but cannot produce electricity. Moreover, the losses associated with the reversible electrochemical storage of energy do not increase efficiency, although their use in hybrid electric vehicles (HEV's) and PHEV's can increase overall vehicle system efficiency. As will be discussed, fuel cells in general, and SOFCs in particular, can be used in the execution of every DOE strategy. With an additional requirement that the technology utilize existing fueling infrastructure, SOFCs stand out as a key cross cutting technology solution.

1.2 US fuel cell RD&D policy

Despite the applicability of fuel cells to each strategy and a historic presence in our energy technology RD&D portfolio, fuel cells appear to play no role and are not mentioned in DOE's Technology Review. The FY 2012 budget request cuts the fuel cell programs in research and development (R&D), data analysis, market transformation and manufacturing R&D, by \$106 million, 65% of their 2010 budget. Almost one half of this cut, \$49 million, is related to the SECA program, and in fact, zeros the program out.

The two primary DOE fuel cell RD&D programs are the Office of Fossil Energy's SECA program and Office of Energy Efficiency and Renewable Energy's (EERE) Hydrogen program. SECA exists to accelerate commercialization of fossil-fueled SOFCs, with current emphasis on large-scale stationary coal power plants. Previously, EERE's Hydrogen program mostly excluded SOFCs and focused on the use of hydrogen fueled proton exchange membrane fuel cells (PEMFCs) for transportation, small stationary and portable devices.[2] With the 2012 budget request, the DOE has apparently rebranded the EERE Hydrogen Program as the Hydrogen and Fuel Cell Program in

Table 1 DOE key strategy and energy technology applicability

DOE Key Strategies	Solar PV	Concentrated Solar	Wind	Geothermal	Batteries	Nuclear	**Fuel Cells**
Stationary							
Deploy Clean Electricity	X	X	X	X		X	X
Modernize the Grid					X		X
Increase Building and Industrial Efficiency	X			X			X
Transportation							
Deploy Alternative Fuels		X				X	X
Progressively Electrify the Fleet					X		X
Increase Vehicle Efficiency					X		X

an effort to create a more fuel cell technology neutral environment, although continuing to link fuel cells with hydrogen.

Despite the over $1 billion investment into EERE's Hydrogen Program, it is now universally recognized that we are still a decade or more from possessing a significant hydrogen refueling and distribution infrastructure. Serious technical and economic issues remain, and thus DOE's explanation for the 2012 Hydrogen and Fuel Cells Program's budget reduction states:

"Hydrogen and fuel cell technologies are still part of the portfolio but will have an impact in the longer term"[3].

The President's call for the rapid electrification of the US transportation fleet, a DOE reliance on PEMFC's for transportation solutions and the recognition that our hydrogen infrastructure is a long-term and costly endeavor, seem to have left DOE with little choice but to shift its focus to hybrid and battery technology and away from PEMFCs. What remains unexplained is why SOFCs are included in this shift.

2. Solid oxide fuel cells and the solid state energy conversion alliance

Fuel cells directly convert a fuel's chemical energy to electrical energy (an electrochemical reaction) with the major focus to date being the use of hydrogen as a fuel. As such, fuel cell technology has become synonymous with hydrogen technology in the public perception and the DOE EERE Hydrogen and Fuel Cell Program. While the more common PEMFCs require hydrogen fueling, since they are based on proton conducting electrolytes, SOFCs are fuel flexible since the electrolyte transports an oxygen-ion that can oxidize essentially any fuel, from H_2 to hydrocarbons to even carbon.

As shown in Fig. 2a, a SOFC consists of three major components: two porous electrodes (cathode and anode) separated by a solid electrolyte. At the cathode, O_2 (from air) is reduced and the resulting oxygen ions diffuse through the solid electrolyte lattice. These ions react with fuel gases at the anode yielding heat, H_2O and (in the case of hydrocarbon fuels) CO_2.

Multiple cells are combined in series *via* interconnects, which provide both electrical contacts and gas channels between individual cells, creating a "stack". This modular structure allows a wide range of power output, from portable power (~100 W) and transportation (~10 kW) to distributed generation (~100 kW) and centralized power (>1 MW), all operating on currently available fuels, as indicated in Fig. 2b.

The most widely used SOFC electrolyte is yttria-stabilized zirconia (YSZ) due to its relatively high oxygen-ion conductivity, and chemical and mechanical stability at high temperatures. Conventional SOFCs operate at high temperature allowing internal reforming of hydrocarbon fuels and without expensive precious metal catalysts (*e.g.*, Pt). In addition to fuel flexibility, SOFCs are 45–65% efficient in the conversion of fuel to electricity[4] unheard of by any other technology. Moreover, since SOFCs generate high-quality waste heat, in combined heat and power (CHP) applications total system efficiency can exceed 85%.[5]

2.1 SECA's role in SOFC technology development and cost reduction

Established in 1999 as a public-private partnership, the SECA program is charged with enabling the commercialization of

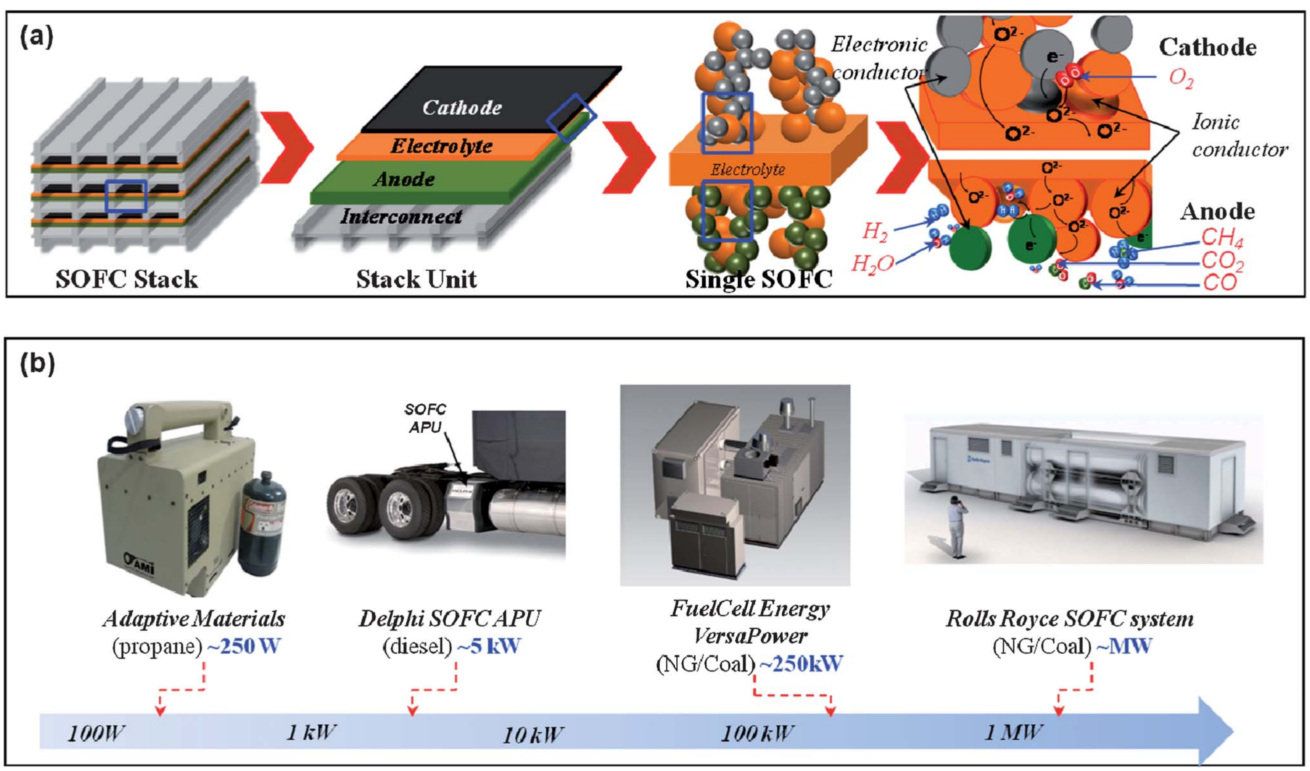

Fig. 2 (a) Schematic diagram SOFC with different magnification from a stack cell to anode and cathode microstructures. (b) Commercially developed portable (250 W) and transportation (5 kW) SOFCs, and larger scale stationary (250 kW and MW) SOFCs planned for commercial demonstration in 2013.

environmentally friendly, cost effective and fuel flexible SOFC modules. The program has three major components: Industry Teams, Core Technology, and federal government oversight (and has been lauded by the Office of Management and Budget as leading the way in Government-industry partnerships). The Industry Team members currently include: FuelCell Energy, Versa Power Systems, United Technology Corporation, Delphi and Rolls Royce. Each team is responsible for their individual fuel cell design, manufacturing, and commercialization strategies. Core Technology (comprised primarily of universities and national labs) has focused on developing technological solutions to issues common to the Industry Teams. The result has been steady progress in increasing cell/stack power densities and reliability while simultaneously driving down operating temperature and costs.

Prior to SECA typical SOFCs had power densities of ≤ 0.2 W cm^{-2} and operating temperatures of $\sim$1000 °C. These operating temperatures required expensive ceramic (*e.g.*, lanthanum chromate) interconnects which for planar geometries dominated the stack cost. Among the numerous SECA technological advances were the development of anode supported electrolyte cells (the resulting thinner electrolyte has significantly lower ohmic resistance) and advanced mixed ionic-electronic conducting cathode materials and microstructures. These have dramatically increased power density and brought temperatures down to the point where inexpensive ferritic steels can potentially be used for interconnects.

As an example, Delphi's 4th generation auxiliary power unit (APU),[6] currently being field trialed, has an anode supported design with ferritic steel interconnects and achieves a power density of $\sim$0.5 W cm^{-2} at 700–800 °C.[7] In contrast, Bloom Energy (which was not part of SECA program) is still using electrolyte supported cells for their distributed generation "Bloom Boxes" and have a reported power density of $\sim$0.2 W cm^{-2} at 900 °C,[8,9] comparable to the pre-SECA SOFC performance. While Bloom uses a metal interconnect, their higher operating temperature requires a much more expensive high-Cr alloy composition and will also have higher BOP costs than SECA industry teams. It is also noteworthy, that the entire DOE SECA budget from 1999 through 2011 is $\sim$\$500M essentially the same as reported for Bloom Energy alone.

As shown in Fig. 3, SECA's synergistic collaboration has driven projected SOFC stack costs from over \$1,500/kW in 2000 to around \$175/kW in 2010. These cost models, consistent with Delphi's results, use a projected power density of $\sim$0.5 W at operating temperatures of $\sim$700–800 °C.[10,11] While SECA's cost reduction efforts have been significant, the rate of change in cost is projected to level off because of shift in focus to scaling up manufacturing of existing cell technology and addressing coal power plant integration requirements, rather than further power density improvements and related cost reductions.

2.2 Global recognition of the competitiveness of SOFC solutions

While the SECA program is currently focused on large-scale centralized coal power plants, the industry teams envision building market and manufacturing scale through a number of smaller-scale initial-product launches (Fig. 2b). These smaller scale applications, such as distributed generation (DG) and CHP residential applications, are the focus of international efforts. Japan's Toyota Motor Corporation and Aisin Seiki Company, LTD are participants in the New Energy and Industrial Technology Development Organization's (NEDO) phase II pilot that is deploying 60 SOFC residential CHP systems as part of their plan to accelerate development during the next five years.[14] Continued government incentives and support of domestic Japanese manufacturers, such as Panasonic, Toshiba and Eneos, have already led to the sale of thousands of residential CHP fuel cell systems.[15]

The Callux program was created by the German Ministry for Transport, Construction and Urban Development (BMVBS) to validate fuel cell heating systems for domestic residential use and has a budget of almost 100 million Euros. Technology project partners include Baxi Innotech (PEMFC), Hexis (SOFC) and Vaillant (SOFC). By January 2011 the program had already installed and operated 111 fuel cell CHP systems and will ramp up to over 800 by 2012, although BOP issues have caused some delay in installations.[16,17]

Similar to the US's SECA program, a European coalition, Cathode Subsystem Development and Optimization for SOFC-Systems (CATION) was formed by Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) to accelerate the market introduction of 250 kWe SOFC systems. Collaborators include: Wärtsilä, AVL, Topsoe Fuel Cell, Bosal Emission Control Systems, and CE.Si.S.P.[18] Another coalition project, SOFC 600, is focused on lowering SOFC operating temperature to 600 °C in order to improve system life and lower manufacturing costs. The two major commercialization tracks are CHP and transportation APUs.

Ceres Power, a spin-off of SOFC 600 partner Imperial College, has developed a wall mounted SOFC that is capable of $\sim$600 °C operation and has started commercial field trials of these residential systems. British Gas has placed notational orders for a minimum of 37,500 systems.[19] Fueling this effort are government incentives; in mid-2010 a feed-in-tariff was initiated for low-carbon residential power generation.[15]

3. Reducing SOFC cost through advances in power density

The two issues that have limited acceptance of fuel cells are reliance on a hydrogen infrastructure and cost. As previously mentioned SOFC fuel flexibility negates the first concern so here we address the second one, cost. Historically, PEMFCs have been considered to cost less than SOFCs as indicated by comparing the EERE/PEMFC and SECA/SOFC cost projections in Fig. 3. Both are DOE projections based on achieving volume manufacturing. However, the EERE projections assume 10X the manufacturing volume of SECA. Moreover, deployment of PEMFC systems requires not only the additional cost of an H_2 infrastructure, but the cost of H_2 storage, whereas, SOFCs would run off conventional fuels with conventional storage.

Another difference between PEMFC and SOFC cost projections are the leveling off of costs beyond 2010. In the case of PEMFC, major cost reductions to date have been due to the reduction in precious metal (*e.g.*, Pt) catalyst loading. This has

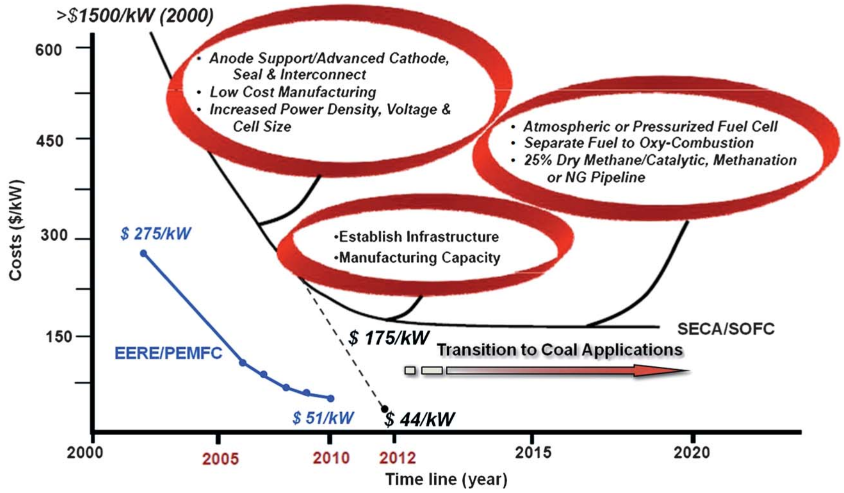

Fig. 3 Fuel cell cost timeline showing reduction in SOFC stack cost after achieving annual production rate of 50,000 5 kW units/yr, and transition to coal development under SECA program;[12] linear extrapolation of SECA cost reduction efforts without transitioning to coal; and EERE projections for PEMFC stack costs after achieving 500,000 units/yr.[13]

resulted in a dramatic decrease in precious metal loading but further potential reductions are limited.

In the case of SOFCs primary cost reductions have been due to increases in power density. The recent TIAX's SOFCs manufacturing cost model found that material costs dominated stack costs[11] and made power density the variable with the most impact. In SECA's Pathway Study an even more direct use[20] of power density's impact on manufacturing costs was presented.[21] The Fig. 3 SECA cost plateau is due to a freezing in of cell technology and shift in focus to coal utilization issues rather than any fundamental limit on achievable power density.

A simple linear extrapolation of SECA cost reductions (dashed line of Fig. 3) indicates a path toward lower SOFC stack costs ($44/kW) than PEMFC stack costs ($51/kW). Since SOFC stack costs are inversely proportional to power density[10,11,21] the indicated reduction of stack cost from $175/kW to $44/kW could be acheived with a ~4X increase in power density. Note, however, total system cost would also include BOP, which doesn't scale directly with power density.

The SECA cost projections are based on a power density of ~0.5 W cm^{-2}. Thus to achieve $44/kW would require stack power densities of ~2 W cm^{-2}. In fact ~2 W cm^{-2} has already been achieved in the lab at the cell level with conventional SOFC materials for 800 °C operation[22,23] and more recently with advanced materials down to 650 °C.[24] While there are a number of scaling issues between laboratory cells and commercial stacks, one could argue that SOFCs have already demonstrated the potential to challenge PEMFCs costs and establish SOFCs in markets heretofore seen as more suitable for PEMFCs.

Moreover, the same cell advances that increase power density can also be used to lower operating temperature with the potential to further accelerate cost reduction. Lower operating temperature significantly expands the available interconnect, seal and BOP materials set. This can have a dramatic effect on cost since interconnects, and not the cell, are the bulk of material in planar SOFC stacks. In addition, lower operating temperature allows lower cost standardized components, reduces BOP failure rates,[17,25] and allows the use of less expensive materials and manufacturing methods for seals, manifolds, and heat exchangers.[5] The balancing of these two factors, higher power density and lower operating temperature, holds the potential to lower the cost of LT-SOFCs further below those for PEMFCs.

4. Expanding applications with lower-temperature solid oxide fuel cells

A major focus of the SECA program has been to lower operating temperature to an intermediate range of 700–800 °C for stationary applications, as a tradeoff between cost and performance while still allowing for internal reforming of hydrocarbon fuels (lower limit to avoid coking is ~600 °C). While this temperature range is good for steady-state base-load operation, it severely limits applications that require transient operation (start-up from ambient temperature), and was in large part why PEMFCs were selected over SOFCs for transportation applications.

For SOFCs, polarization (or impedance) increases with decreasing temperature for a given cell material set thus decreasing power density and increasing the cell area necessary to achieve a desired system power. For example, an SOFC with a conventional YSZ electrolyte would exhibit a 100X increase in ohmic polarization by reducing operating temperature from 900 °C to 500 °C.[26] Because resistance is directly linked to geometry, anode supported thin YSZ electrolytes have successfully reduced ohmic polarization at intermediate temperatures. However, further reduction of operating temperature to <650 °C would require the use of electrolyte thicknesses below 1 μm, which introduces significant manufacturing cost and mechanical stability issues.

Therefore, alternative higher conductivity electrolytes are necessary to further lower temperature. Moreover, use of alternative electrolytes also requires development of compatible electrode materials, and if the electrolyte impedance is no longer limiting cell performance then it is electrode polarization that limits cell performance.

The Ceres Power SOFC CHP system (mentioned above) operates at ~600 °C through the use of a ceria based electrolyte and compatible electrodes. Similarly numerous other groups are developing lower temperature SOFCs based on alternative electrolytes and electrodes.[27] Among these we have demonstrated the highest power density of ~2 W cm^{-2} at 650 °C using a novel bilayer ceria/bismuth oxide electrolyte.[24,26]

For transportation applications specific power (acceleration) and specific energy (range) are key performance metrics. For electrification of the fleet these performance metrics for energy storage devices (batteries) are typically compared in a "Ragone Plot" against EV, HEV, and PHEV goals, and an IC engine benchmark (Fig. 4).[28] Using cell and interconnect thicknesses of 0.5 mm and 1.5 mm, the stack volumetric and gravimetric (specific power) power densities of our recently reported 2 W cm^{-2} cell are ~10 kW/litre and ~3 kW kg^{-1}, respectively.[26] Therefore, if system parasitic losses are ignored our stack power density exceeds that of internal combustion (IC) engines. Clearly this is an over-simplification, but at least it indicates the potential to exceed any other storage technology on a specific power basis. Since both SOFCs and IC engines can be fueled by hydrocarbons, they share a comparable specific energy density. This is much greater than any of the batteries (or EV goals), and is also much greater than PEMFCs (indicated by "Fuel Cells" in Fig. 4) due to the lower specific energy density of H_2. Moreover, while the specific energy densities of liquid fueled SOFCs and ICs are comparable, the factor of ~3 higher efficiency of SOFCs in fact provides the opportunity of ~3X further range (the more important metric for the vertical axis) than an IC engine on the same quantity of fuel.

Traditionally, the relatively long warm-up times and degradation caused by thermal cycling have been considered major weaknesses of SOFCs and represented significant impediments for their use in transportation applications. Several papers have been published illustrating methods for overcoming these temperature issues by utilizing continuous operating SOFCs as a range extender in a battery/fuel cell hybrid arrangement.[29,30] Lower temperatures further open the possibility of matching SOFCs thermal cycling capabilities to the needs of the typical transportation mode's requirements.

As indicated above we have achieved sufficient specific power and energy density for transportation applications. In addition, we have developed electrolytes that have high enough conductivity to allow ~300 °C operation[31,32] if electrodes with sufficiently low polarization are developed. Further discussion of the technical advances necessary to achieve low-temperature operation is available in ref. 26. This would allow the integration of SOFCs into transportation as an effective range extender operating within our existing fueling infrastructure.

5. SOFC applicability to DOE's 6 key strategies

Given the status of SOFC RD&D described above we now focus on the applicability of SOFCs to address each of the 6 key strategies identified in the DOE Quadrennial Technology Review (QTR). The unique attributes of SOFCs, high efficiency, high quality exhaust heat, and fueling flexibility, are shown to be central to DOE's mission. The improved characteristics of LT-SOFCs strengthen the argument in almost every strategy by both expanding the possibilities and lowering costs.

5.1 Stationary energy - deploy clean electricity

The underlying purpose of the three stationary strategies is to enable access to clean electricity while reducing emissions associated with traditional sources. Worldwide, electricity represents the fastest growing segment of energy usage.[33] Over the next 24 years, the International Energy Agency (IEA) forecasts that global electricity usage will triple from a 1990 base. Two major trends will help to drive this increase. First, in 2008, 22% of the world's population, around 1.5 billion people, did not have access to electricity. The benefits associated with electricity will place increasing political demands on governments to provide electrification. Second, the electrification of the transportation fleet, whether caused by policy or shortages of conventional liquid fuel, will add significant demands to electrical production capability.

Today, 50% of the US's electricity is produced from coal and 20% from natural gas.[1] Our large reserves, and current lack of economically competitive alternatives, suggest that a sizeable

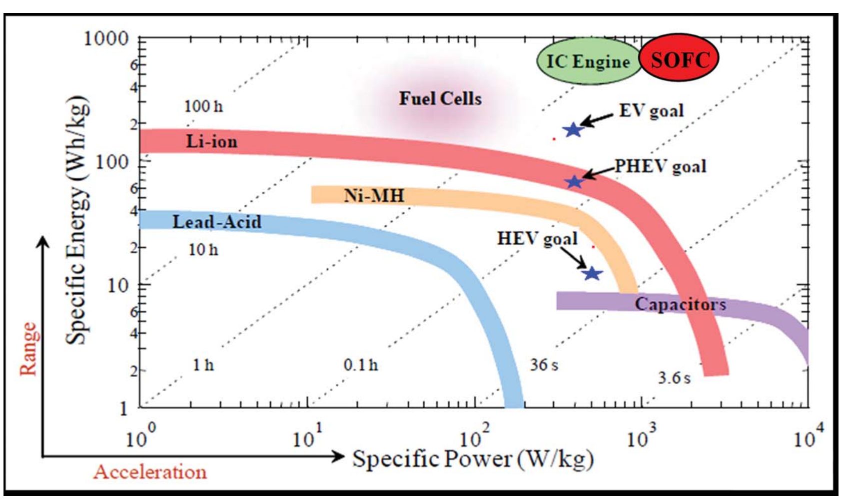

Fig. 4 Ragone Plot: Specific energy *vs.* specific power[28] adapted to show performance of recently reported SOFC.[26]

portion of our future electricity will continue to be derived from these two sources. Globally, the forecast for electricity generation provided by the IEA is modeled under three scenarios: 1) Current Policies, which assumes business as usual, 2) New Policies, which incorporates announced broad policy commitments and plans that effectively limit increases in global primary energy demand to 36% between 2008 and 2035, or 1.2% per year on average,[35] and 3) 450 Scenario, which includes policies designed to lower CO_2 to 450 ppm. Fig. 5 shows that in 2035, under the New Policy scenario, coal and natural gas are projected to fuel nearly one-half of global electricity generation. Even in the 450 Scenario, coal and natural gas are responsible for one-fourth of global generation. Recently, the IEA suggested that natural gas may comprise 50% of global energy use by 2035.[36]

If electricity production remains dependent upon coal and natural gas, the sustainable use of these fuels and environmental emission reduction goals both require that we utilize these resources with the highest possible efficiency. While natural gas turbine technology has made significant progress and has efficiencies around 50%, coal technology still lags. Utilizing synthetic gas (syngas) derived from coal, SOFCs have potential efficiencies rivaling those of natural gas turbines. While many set a goal to eliminate our use of coal and natural gas, prudence suggests we ensure that their use is as efficient as possible until that goal is achieved.

DOE's QTR strategies address our continuing reliance on coal and natural gas only through Carbon Capture and Storage (CCS) and do not include stationary fuel cells as a potential source of electrical generation.[1] Instead, DOE focuses on nuclear, wind, concentrating solar and solar photovoltaic as the primary displacement sources of electricity. With the exception of nuclear, these technologies all suffer from low capacity factors and intermittency of operation. The large-scale integration of intermittent generation into the grid will require significant advances in energy storage and demand control technologies, technologies whose commercialization may not be as mature as that for fuel cells.

SECA has been DOE's signature large-scale stationary fuel cell program until this budget request and has focused on using coal-derived syngas for centralized electricity generation. The June 2010 DOE Hydrogen and Fuel Cell Technical Advisory Committee (FCTAC) progress report reflected that SECA's lab-scale 25 kWe SOFCs had completed 5,000 h of testing on simulated coal syngas, and factory cost estimates developed for a baseline 560 MW Integrated Gasification Fuel Cell Cycle (IGFC) power plant were ~\$400/kW (in 2002 dollars) for the SOFC power island and a \$119/kW[37] SOFC stack cost.

DOE's 2011 IGFC Pathway Study "Analysis of Integrated Gasification Fuel Cell Plant Configurations" quantified the projected performance and cost benefits associated with the technology and made the following conclusions:

- Fuel to electricity efficiency (HHV) ranged between 40% and 51%;
- Raw water consumption was less than 50% of conventional fossil fuel power plants, ranging from 2.05 gpm/MW to 3.07 gpm/MW;
- CO_2 emissions ranged from 1.3 kg/MWh to 2.5 kg/MWh;
- First year levelized cost of electricity (LCOE) ranged from \$71.2/MWh to \$96.3/MWh, and
- IGFC was potentially cost comparable to natural gas combined cycle *without carbon capture and sequestration*.[21]

As shown in Table 2, a new pulverized coal power plant with CCS has significantly lower efficiency and approximately double the levelized cost of electricity (LCOE) as an IGFC power plant.[21,38] The IGFC's CO_2 emissions are almost three orders of magnitude below those of a pulverized coal plant without CCS, which range from 750 kg/MWh to over 1,000 kg/MWh.[39] For all practical purposes, IGFC CO_2 emissions are comparable to those of a pulverized coal plant with CCS. Thus, an IGFC's

Table 2 - Performance of IGFC against pulverized coal

Metric	IGFC	Pulverized Coal w/CCS
Efficiency (HHV)	40–51%	28.40%
Raw water consumption (gpm/MW)	2.05–3.07	10.7
CO_2 emissions (kg/MWhour)	1.3–2.5	~0
LCOE (\$/MWhour)	\$71.2–\$96.3	\$150

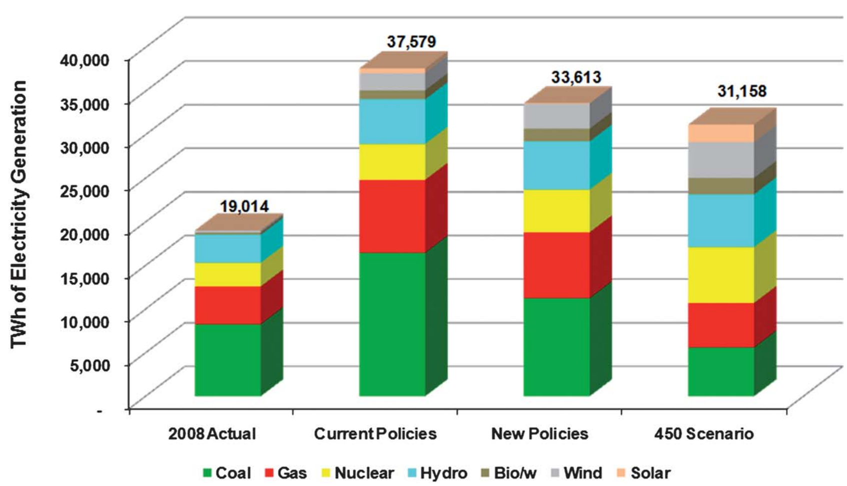

Fig. 5 - IEA Forecast Global Electricity Generation by source.[34]

performance equals or exceeds every performance metric of a CCS coal plant.

Similarly, Adams and Barton described a process to replace natural gas turbines with SOFCs that resulted in 74% efficiency (HHV), zero atmospheric emissions, low water use, and an LCOE below existing natural gas combined cycle without carbon capture.[40]

Despite the clear advantages of SOFCs for large scale fossil fuel generated electricity, the proposed FY 2012 budget will delay the demonstration and testing of SOFC modules from 2013 to 2015 and suspend all new core technology efforts during FY 2012, adversely impacting the industry and R&D teams that have been assembled under the SECA program. Finally, this postponement will impact each of DOE's Stationary Energy strategies as SECA planned to enter the distributed generation (DG) and CHP markets following the 2013 demonstration.

5.2 Stationary energy - modernize the grid

Differences between the physical characteristics of new and traditional electric generation technologies impose significant issues on the grid's ability to function. A primary concern is the variability of electrical output from renewable resources such as wind and solar. The large-scale integration of these resources will require the ability to reversibly store energy and/or rapidly alter loads. Dispatchable DG will play an important role in the solution.

Challenges associated with modernizing the grid can be greatly reduced by leveling the variation between peak and trough loads, or smoothing the loads. The US's electrical grid was developed to facilitate access to electricity from centralized generation plants. Its design requires significant over capacity in order to handle loads that may occur for less than an hour in an entire year. The grid's daily and seasonal load patterns are fairly consistent and are primarily related to residential and commercial activity patterns as these sectors represent the majority of electricity usage. The peak of the peak electricity usage occurs during the summer when demand for interior space cooling is the highest. Daily residential patterns reflect demand concentrations during the morning and evening hours. Not surprisingly, peak hot water usage closely follows peak electricity usage.[41]

DOE readily acknowledges that DG systems will play a significant role in improving the grid's flexibility and performance.[1] SOFCs are ideally suited for DG because they can operate with the existing natural gas infrastructure and, unlike gas turbines, SOFCs' high efficiency is less dependent on installation size and can be scaled down for distributed applications.[42]

Experimental work at the National Energy Technology Laboratory's (NETL's) Hybrid Performance project has shown that SOFC/gas turbine hybrid systems have strong load following capabilities while maintaining high system efficiency. The project has reported up to 69% peak to trough system operating range,[43] quick recovery from a full load rejection and the ability to provide spinning reserves without parasitic drain on fuel supplies.[44] Thus SOFC/turbine hybrids can play a major role in assisting the deployment of renewable generation into the grid. Moreover, LT-SOFC's would increase load following flexibility due to faster starts-ups and decreased thermal stresses.

In addition to DG, reversible SOFCs (RSOFCs) can be used for grid storage. RSOFCs can produce H_2 by electrolysis from intermittent (*e.g.*, wind and solar) and/or from base-load generation when electricity is not in demand, and when electricity is again needed the H_2 is used to generate it. A major benefit of RSOFCs is that "combining the electrolysis and fuel cell into a single unit will cut capital costs in half".[45] DOE project, FC042 – "Advanced Materials for RSOFC Dual Operation with Low Degradation" is working towards integrating production of H_2 with intermittent solar and wind electrical production to stabilize electricity production.[46]

5.3 Stationary energy - increase building and industrial efficiency

There are two distinct approaches to energy efficiency. The first is the conservation of energy by not using it in the first place. This is the major approach advocated by DOE in their focus on building design, energy management and building envelope and windows. Another approach is to reduce losses associated with the use of energy, such as the conversion of energy to electricity. In 2009, 68% of the energy used to create electricity was lost as waste heat.[47] The use of SOFCs for electrical generation, particularly CHP, would result in a significant reduction of waste heat due to their higher efficiency. Just improving our electrical generation efficiency from 32% to 50% would have reduced our total nation's energy consumption around 15% in 2009 (almost 14 quads).

NREL's 2010 "Independent Review of Fuel Cell CHP technology Status and Potential" concluded that only SOFC based CHP systems were likely to meet the DOE 90% combined efficiency target.[5] Similarly, the National Fuel Cell Research Center modeled an 87.5% efficiency for SOFCs while providing flexible peaking power to the grid[44] and in 2009 Japan's New Energy Foundation program verified over 70% combined efficiency from SOFCs under actual load conditions.[48]

Due to adverse environmental impacts of most commercially used refrigerants, it is quite likely they will eventually be banned. More environmentally acceptable refrigerants have lower performance and will require technology development in vapor compression systems (VCS). Both factors strongly favor RD&D towards heat-activated cooling devices.[49] NREL's independent review panel for fuel cell CHP called for DOE:

".. to formulate a long term (5-year) plan for research and development, scale-up, and field testing. To initially generate large order volume, the fuel cell units could be installed at national laboratories and government buildings."

While CHP creates both usable heat and electricity, "trigeneration" creates usable heat, electricity, and cooling, from a single fuel source. The coupling of cooling, through absorption, adsorption or desiccant technologies, has the potential to significantly improve the overall efficiency of electricity production, and this is particularly true with LT-SOFCs. Since the fuel source is now providing three services; heating, cooling and electricity, capital costs can be spread over a much larger base.

In 2009, residential and commercial sectors consumed more than 75% of the generated electricity and just over one third of the natural gas used that year.[47] The top four usage categories for these sectors were space heating (25%), lighting (19%), space cooling (12%), and water heating (11%).[50] Thus, almost 50% of the two sectors' energy use is related to heating and cooling their interior or water. To accomplish these tasks requires a major part of the nation's electricity and one third of our natural gas.

CHP and trigeneration can be deployed in both centralized and distributed environments. Currently 50% of Denmark's electricity is produced by mostly centralized CHP (8% in the US).[44] Illustrated by the growing number of successful pilot applications around the globe, the best near-term opportunity for SOFCs may be in distributed CHP and/or trigeneration.

This single application addresses all three of DOE's Stationary Energy strategies and illustrates SOFCs' cross cutting capabilities. SOFCs produce a kWh of electricity from hydrocarbon fuel more efficiently and therefore have fewer emissions than traditional generation. The utilization of previously discarded waste heat, especially in distributed applications, to both heat and cool interior spaces aids in increasing building efficiency while helping to lower the grid's peak demands. Thus, a significant penetration of distributed SOFC trigeneration would lower summer peak demand, lower daily peak demand, provide a distributed base of manageable electricity generation, reduce our use of fossil fuels, and lower emissions.

The optimum characteristics for trigeneration are a heat source[52] above 150 °C, and a consistent and single flow of heat, *e.g.* exhaust. The three best heat sources for trigeneration are turbines, high temperature PEMFCs, and SOFCs.[49,51] Fig. 6 shows the heat source technology and its temperature range. The efficiency of the process can be determined by finding the intersection of the needed temperature and the heat source's range. As an example, for a heat-activated device, such as a double effect chiller operating at 150 °C, SOFCs' high quality heat will enable about 45% of the fuel's energy to be utilized by the chiller, in addition to the already generated electricity.

LT-SOFCs are the ideal heat source for trigeneration as their lower temperatures remove the requirement for exotic and costly components and yet their temperature remains high enough to drive double or even triple effect chillers.[51] Presently there are no commercially available micro-turbines (MT) under 25 kW nor are there commercially available HT-PEMFCs. Since LT-SOFCs

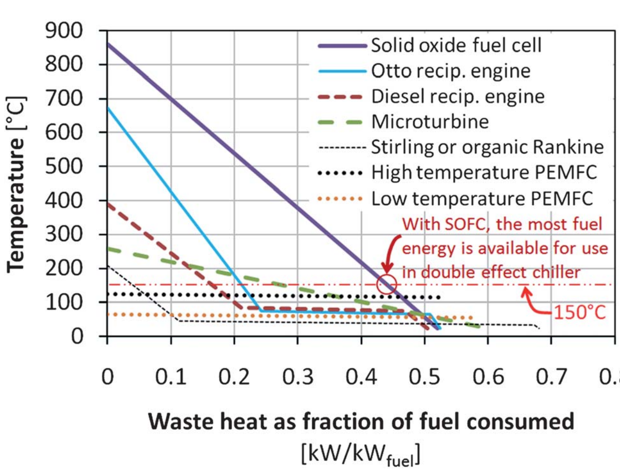

Fig. 6 Available waste heat energy as fraction of fuel energy at temperature.[51]

are the ideal heat source for distributed trigeneration, a focus on LT-SOFCs RD&D seems warranted.

The key question: can LT-SOFCs and trigeneration become economically competitive? Numerous studies reflect SOFCs CHP's near cost competitiveness with conventional sources. In particular, a 2010 American Society of Mechanical Engineering (ASME) published paper, using an estimated cost of $2,268/kW, concluded that a SOFC powered CHP has life cycle costs comparable to conventionally generated electricity even without environment or beneficial distributed generation impacts. Since the paper did not address trigeneration, potential benefits associated with cooling would be additive.[53]

Clearly, the adoption of LT-SOFC CHP and trigeneration should be strongly advocated by DOE as a meaningful efficiency improvement for both residential and commercial users.

5.4 Transportation - deploy alternative fuels

The underlying purpose of DOE's three key transportation strategies is to reduce dependency on oil (energy security) while reducing emissions. One approach to achieve these goals is the deployment of alternative fuels, which presupposes that there will be devices that can utilize those fuels. While a goal is to find a sustainable "drop-in" fuel to replace gasoline and diesel, to date there has been limited production with the exception of ethanol. Much of our transportation fleet cannot operate with high blends of alcohol fuels. Moreover, IC engines are designed to be fuel specific (*e.g.*, a diesel engine cannot operate effectively on gasoline and *vice versa*). In contrast SOFCs are fuel flexible, having the capability of utilizing all existing fuels (*e.g.*, natural gas, gasoline, diesel) as well as all envisioned alternative fuels (*e.g.*, H_2, ethanol, biodiesel) with the appropriate pre-reformer. This fuel flexibility is critical to the deployment of alternative fuels that may, particularly for biofuels, be geographically dispersed (*e.g.*, ethanol in the Midwest) since the consumer expects to be able to drive (and fill) their vehicle anywhere in the contiguous U.S.

In addition, SOFCs can be used in the production of alternative fuels. RSOFCs produce H_2 from H_2O in the electrolysis mode (as mentioned above for grid storage) and have already shown the ability to achieve the 2017 DOE fuel cell targeted goal of 75% efficiency for H_2 production from electricity and water.[46] While this efficiency is still low, and degradation issues remain, RSOFCs have significant potential in the production of H_2 needed for alternative fuels. Similarly, SunFire, the developer of a process to generate renewable fuels from CO_2 and H_2O, has acquired Staxera, a German SOFC company, to gain access to SOFC technology for use in its process to create liquid fuels. The economic viability for Sunfire's process is dependent upon highly efficient electrolysis for the generation of H_2, which both companies believe can be obtained *via* solid oxide electrolyzer cells (SOECs).[54]

Polygeneration energy systems take this one step further by converting conventional energy sources into multiple usable energy products, *e.g.*, liquid fuels and electricity. This approach holds the potential to co-generate petroleum substitutes and electricity from abundant coal and natural gas resources, and its flexibility enables fuel/electricity production to follow demand. SOFCs are particularly suited to polygeneration due to their high electricity generation efficiency and their inherent ability to separate CO_2. SOFCs are "carbon capture ready" since the anode exhaust stream is essentially pure CO_2 and condensable H_2O. Thus even using air as the oxidant, SOFCs can easily, and with little energy penalty, capture CO_2. Adams and Barton modeled several polygeneration methods using both SOFCs and gas turbines as the electrical generation method and found that with carbon capture, SOFCs had total system efficiencies 10% higher than gas turbines and 2% to 4% higher without capture.[55]

5.5 Transportation - progressively electrify the fleet

DOE has claimed that partial electrification of our fleet can reduce domestic fuel consumption by 80 billion gallons annually (over 50% of usage) in 2035.[1] The current degree of vehicle electrification varies from the Toyota Prius and Ford Escape *parallel* hybrid electric vehicles (HEVs) with ICE and battery propulsion combination, to the Chevrolet Volt and Fisker Karma *series* plug-in HEVs (PHEVs) with ICE range extender, to the Nissan Leaf and Tesla 100% electric drive (EV) automobiles. However, a major public acceptance issue for EVs is "range anxiety" thus the earlier adoption of hybrids.

With hybrids, range is extended by consumption of a fuel, currently gasoline but potentially biofuels and one day H_2. In fact, any fuel cell vehicle would be a hybrid, in most likely a series configuration, with a fuel cell (range extender)/battery combination providing power for the electric motor. Despite, DOE's recent de-emphasis of fuel cells and H_2, numerous auto manufacturers plan to begin selling PEMFC powered vehicles as early as 2015.[56] This change in DOE emphasis from fuel cells to batteries is due to concerns about the feasibility and timescale of building a national H_2 fueling infrastructure. DOE's historic focus on PEMFCs, which cannot survive even trace amounts of CO in their fuel, can be linked to the common misconception that H_2 is a prerequisite for all fuel cells. While DOE's decision to reduce RD&D for PEMFCs due to concerns about the hydrogen infrastructure may have some merit, scaling back SOFC RD&D for the same reason does not since they are not dependent upon H_2 as a fuel.

SOFCs are already beginning to make an appearance in transportation solutions as evidenced by Delphi's diesel fuelled 5 kW SOFC APU for large trucks. This system is designed to allow electrical loads to be offloaded from the truck's primary diesel ICE, in effect a parallel hybrid configuration. Benefits include a 40%–50% improvement in fuel efficiency, low emissions and low noise. While Delphi is experiencing issues with the BOP, they are continuing their plans for full scale production of diesel fueled SOFCs for heavy-duty truck applications.[25] The successful commercialization of APU's will lay the groundwork for future mobile applications.

Despite Delphi's APU progress, SOFCs have not been considered a promising technology as the primary transportation power source for two fundamental reasons. First, current high operating temperatures require a warm-up period that can be measured in hours, clearly not in alignment with the average US vehicle's usage patterns. Second, even with faster warm-up times, the SOFCs' high operating temperature causes significant thermal stress on the components when cycled on and off which can cause performance degradation and even system failure.

However in a series hybrid configuration, where primary power is provided by the batteries, operation of the range extender can be independent of driving cycle since it is only used to charge batteries, thus allowing for longer start-up times and less thermal cycles. In this mode SOFCs can perform as a range extender on existing fueling infrastructure thus addressing "range anxiety" and helping to electrify fleet.

Moreover, the improved thermal characteristics of LT-SOFCs greatly expand the possibility of their use in transportation applications. The significant improvement in power density effectively allows a trade-off between temperature and power, thus enabling the retention of an acceptable power level at lower temperatures, potentially down to 350 °C.[26] If these efforts are even partially successful, they promise to reduce thermal stresses and degradation experienced by the system and will obviously reduce the time and energy needed to warm-up the system.

5.6 Transportation - increase vehicle efficiency

HEVs and PHEVs by their very nature provide a platform to increase vehicle efficiency. The question is what are the most efficient "well-to-wheels" methods to charge their batteries?

In the case of PHEVs, if the electricity is produced inefficiently from hydrocarbons (*e.g.*, conventional coal plant) the combination of the coal power and the PHEV drive system holds little real efficiency, or emissions, gains compared to a gasoline fueled ICE hybrid.[57] As discussed in Argonne National Laboratory's study on PHEV well-to-wheels efficiency and emissions, coal dependency for electrical generation could result in the PHEVs using more energy and emitting more greenhouse gases than conventional gasoline hybrids. Moreover, it is expected that PHEVs and EVs will utilize off-peak (night-time) electricity generation shifting more electrical generation to base-load coal fired plants. Since IGFC holds the promise of the highest coal to electricity efficiency SOFCs have a significant role to play in increasing vehicle "well-to-wheel" efficiency.

As a range extender in a series hybrid, IC engines are limited by Carnot efficiency to ~20% (fuel energy to mechanical work)[58] and have further efficiency losses in converting mechanical work to electricity *via* the generator. In contrast SOFC (direct fuel energy to electricity) efficiency is 45–65%,[4] thus a 2–3X increase in efficiency compared to IC engines. However, these efficiency gains are offset in part by the energy required to heat the SOFC to operating temperature, thus the further need for LT-SOFCs.

With the highest potential efficiency, LT-SOFCs can be used to increase efficiency for both electric vehicles and vehicles powered by alternative fuels. These efficiency gains can be provided by supplying the vehicle's fuel, electricity or alternative, or by directly powering the vehicle.

Currently, the technical maturity of PHEV and ICE hybrid technology is significantly more advanced than LT-SOFC technology although the market penetration of PHEV into the light-duty US transportation fleet is only expected to reach 25% by 2020.[57] Given this relatively long gestation period for the electrification of our transportation fleet, the US has a window of opportunity to develop LT-SOFCs as a source of primary power generation.

With the impact of electricity generation on EV and PHEV efficiency and emissions, the reliance upon base-load electricity for recharging and the time necessary to convert our fleet to electricity, the US is well served by ensuring that the efficiency and emission improvements of SOFCs are a significant portion of our electricity generation.

6. Conclusion

Even the most optimistic forecast does not suggest the elimination of fossil fuels in the foreseeable future. Absent drastic political and economic changes, the US's large coal and natural gas reserves will continue to be used as a primary energy resource. Therefore, the shared goals of resource conservation and emissions reduction, as well as plain common sense, demand that their use be as efficient as possible. Current SOFC technology has the highest efficiency and lowest emissions when using conventional fuels and can readily transition to alternative fuels as their fueling infrastructure is created.

Moreover, no other major energy technology is as versatile as SOFCs, which are able to play a meaningful role in each of DOE's six core strategies. Successful commercialization of APU, CHP, DG, and similar applications through SECA will lay the foundation for future innovation and cost reductions in SOFCs. Around the globe, meaningful pilots and commercialization activities are expanding in the use of SOFC driven CHP. Abandoning, or even delaying, investments into this cross cutting technology just as it is becoming commercially viable are not in our short or long term interests.

The near quadrupling of power density enabled by recent progress in the lab provides significant room for lowering SOFC operating temperature. Such temperatures dramatically expand applications and reduce cost, thus, fundamentally altering the fuel cell paradigm. LT-SOFCs provide the opportunity to obtain all of the anticipated fuel cell benefits without waiting for a H_2 infrastructure.

DOE's full embracing of SOFCs, and extending it to include LT-SOFCs, has significant benefits beyond the more efficient and less polluting use of our natural resources. The restoration, or increase, of the fuel cell RD&D budget will protect our long-term billion dollar commitment to fuel cell technology, provide clarity to the public and stakeholders regarding our fuel cell vision, facilitate a promising technology on the cusp of commercialization and maintain the critical mass of talent that has been assembled with SECA and other promising commercial interests. All of these benefits can be seen as fundamental attributes for a successful national energy RD&D program.

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Mary Lasky's Comments for August 28, 2012

It is everyone's obligation to do whatever is possible to be prepared for a disaster. Being prepared is something that we can strive to do so that both the individual and the country can be resilient when disaster strikes. John Kennedy stated it so beautifully, "Ask not what your country can do for you but what you can do for your country."

We as a nation have become too dependent on the government being there and taking care of us. There are situations in which it can and will and situations when it cannot. We had a recent example of this when the violent storm at the end of June -- the Derecho. When the power went out and a Virginia 911 center was knocked out. Consequently, we need to be prepared as citizens and as businesses.

As citizens we need to prepare ourselves to be resilient and we need to help our neighbors during disasters. Being prepared means having food, water, hand cranked radios, flashlights, medication to be able to shelter at home and all of these types of preparations ready if you need to evacuate our homes. Having preparations in your car and at your office is also important. So my first short-term recommendation is that citizens should have supplies for at least three days. This is short term. In a major catastrophe, people might need to sustain themselves for weeks or even months.

Businesses need continuity plans. A first step in creating them to examine their risks and work to mitigate them. The lack of electricity is certainly one potential risk. Having a generator is important for many businesses, such as filling stations so that they can continue to pump gas when the power goes out or food markets need to keep food supplies from spoiling and serve the community.

One of my long-term recommendations is for businesses to create a business continuity plan. There are many different resources for businesses to help them with continuity planning so that they will be resilient. The Red Cross has material, FEMA has material, the Chamber of Commerce has material. One of the things we found at the Applied Physics Laboratory is the benefit of having a high level view of your plan contained on a single page and creating trigger points so that essential actions are taken at the right time. The Howard County Community Emergency Response Network (CERN) has a series of templates available to businesses that present a model for a one-page plan. That can be found on the CERN web-site. Those businesses that had a plan on 9/11 are in business today.

There are certain disasters that might take down the electrical grid that would result in being without power for a week, or a month or even longer. Consequently, we need power companies to harden the grid. It costs businesses and government billions of dollars when the power goes out for a period of time. It would cost the electrical power companies billions to harden the grid. Our country's critical infrastructure is based on having electrical power. Our banks cannot work without power. Our food is dependent on power for refrigeration; our military depends on electronics; our medical work cannot provide care without power. Consequently, the nation depends on the power grid. Another of my long-term recommendation is hardening the electrical grid nation-wide should be a high priority goal.

But, what can citizens do in the long-term to help if the grid does go down for weeks or months? It has been estimated that realistically we could meet 20% of our electrical needs off the grid. Citizens can do this by having generators for emergencies and installing solar panels on our roofs we can eliminate some power needs, Growing some of our food would also be of benefit. So my third long-term recommendation is to encourage a citizen movement in the country where we are all prepared and we could survive— by creating some of our own power. – perhaps 20%. However, this is not an easy goal in our modern cities. How would apartment dwellers accomplish this? The current economic situation means that many people do not have the discretionary money to invest solar power or generators or creating a garden.

Unless there is a true movement to promote resiliency as essential to people's security and independence, people will be not feel an obligation to invest and change their life styles. But if we are to be able to survive natural or man-made catastrophes or disasters as individuals, as communities, as a nation, then it is essential that we take the kind of steps, I have recommended.

And let me repeat that we as a county/region/state to be more resilient one of the most important steps is that the electrical power industry harden the grids, at all levels, against storm, and against knock out EMPs caused either by solar activity or high altitude nuclear explosions. We are currently in the middle of a solar cycle of high sunspot and solar storm activity, which will peak in 2013. A coronal mass ejection (CME) occurring today could knock out the entire national electrical power grid for months. Citizens and businesses need to do their part. The power industry needs to do their part.

Maryland Conference on Reliability

August 2012

Introduction

SGS is a new Company HQ in Rockville and comprised of a team of solar veterans and battery experts.

We develop and finance energy storage solutions for DG solar.

- Enable high-penetration of DG renewable energy
- Lowers net effective cost of solar energy
- Integrate energy storage into PV installations where on-site storage provides value to the system host and the utility grid
- Our message: "we make it better with batteries"

SolarGrid Storage

What We've found

- Great desire to add storage at solar customer sites
- Customer's routinely ask if they install solar whether they will have power during outages
  - Traditional system "NO"
  - With batteries "YES"
- Allows critical loads to be served 24/7 during grid outages and major loads during periods of sunlight

Markets for Solar w/ Storage

- SGS is focused on the commercial sector with plans to add residential
  - We can add storage to any solar project
  - Improve investment returns on **ALL** solar projects
- High-penetration solar areas (Utility)
- Property Developers
  - Home builders; Property managers; REITs
- Military & Government
  - DoD; Military Housing; Local Governments

SolarGrid Storage

What We Do

- Finance battery additions to Solar PV installations – no upfront cost to solar customer
  - Commercial Scale
  - Utility Scale
  - Pending – residential
- Reduce the cost of the solar installation through a shared inverter (DC to AC power conditioning)
- Earn revenues by providing grid services
  - PJM ancillary services markets
  - Section 48C Investment Tax Credit (ITC)
    - Must be co-located with solar or renewable project
  - Payments from host customers
    - Backup power
    - Peak shaving
  - Possible - Local Utility payment for smart grid support (voltage/VAR; data)

SolarGrid Storage

We support the electric grid

- Local grid value
  - Outage support
  - Real time Voltage and VAR adjustment
  - Solar power export smoothing
- Smart grid value
  - Real time voltage data, PF data, power flows
- Reduced post-outage in-rush current
- ISO (PJM) ancillary services support
- Blackstart potential

Working with LDC’s - Stability

- Utility control of solar/battery inverter and storage in real-time to address:
  - Too much real-time solar power on distribution circuits
    - Valuable in high-penetration solar areas
  - Real-time Voltage/VAR needs
    - Battery inverter system much faster response than voltage regulators and limited wear & tear
    - Ties into local SCADA system
- Future micro grid potential

Recommendations

- Initiate a pilot program for solar w/ storage
  - Could include incentives to add batteries to solar projects e.g. SREC adder of 25%
- Undertake Utility/PSC evaluation of potential for storage and solar to provide grid benefits
  - Smart grid value and inclusion in smart grid programs
- Authorize and encourage utilities to purchase grid services provided by storage including long term contracts

<u>Summary – Testimony of Christopher Cook, President, Solar Grid Storage LLC</u>

Thank you for the opportunity to testify today. My name is Christopher Cook and I am President of a new start-up company called Solar Grid Storage. We are headquartered in Rockville MD and our business is to finance and develop battery storage solutions and systems for addition to solar installations.

Solar installations have seen great growth in Maryland and other states with active programs to promote solar energy use. However, the solar electric systems typically installed do not include a storage element and therefore cannot be used to produce electricity for customers during utility grid outages. By adding a battery storage device, these systems can produce usable electricity both during daylight hours and for either limited periods or for limited loads when the sun is not shining. This increases the value of solar energy systems because now they provide limited electric service to customers when the utility grid is down. Because the solar will recharge the customer's batteries each day, customers with solar and storage installations are somewhat insulated from grid outages even of very long duration.

Solar Grid Storage offers a unique solution to customers since we finance the battery installations. This means it costs a solar project developer or solar customer nothing up front to add batteries. Because we use a common power conditioning device called an inverter (it converts direct current power from a solar or battery system into grid quality alternating current electricity), we save on the installation costs of a traditional solar electric installation. For a customer who desires backup power service, we charge that customer a small monthly fee.

Solar Grid Storage is comprised of a team of solar veterans with entrepreneurial and battery expertise. This combination of in-depth industry knowledge has allowed us to combine the necessary financial expertise with technical understanding to provide cost effective storage solutions for solar installations that will last as long as the solar systems are in use. We are a technology agnostic company and use inverters and batteries from a variety of manufactures provided those manufacturers provide sufficient quality, warranties and price. Our current manufacturers are domestic companies located in New Jersey and Michigan.

We believe that adding storage to solar is the next chapter of the solar industry and will transform solar into a premium power product for customers and is a solution for an unreliable grid. We also support utilities directly in providing real time energy services and data that can make a grid more reliable. In the future, micro-grids supported by solar and storage can allow for partial service to be restored almost immediately to small areas after catastrophic events have taken down the utility grid. A solar supplied micro-grid could, in theory, provide local service for days or weeks while the utility grid is being repaired.

How Microgrids Can Improve Reliability and Resiliency

State of Maryland
Gubernatorial Task Force on Electricity Reliability
August 28, 2012

Benjamin F. Hobbs

Schad Professor of Environmental Management, Whiting School of Engineering
Director, Environment, Energy, Sustainability & Health Institute (E^2SHI)
The Johns Hopkins University

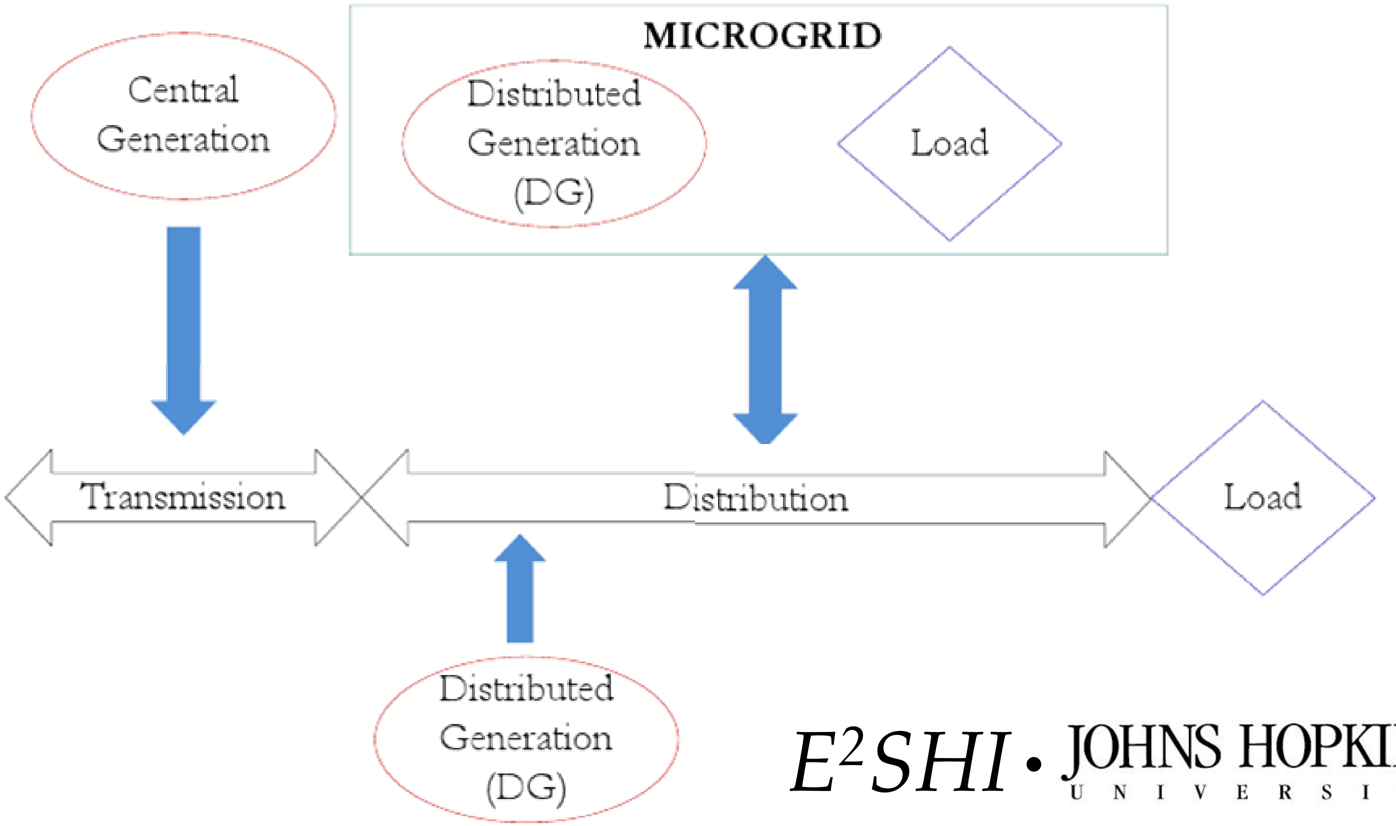
Chair, Market Surveillance Committee
California Independent System Operator

E^2SHI • JOHNS HOPKINS UNIVERSITY

Definition

"A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid.

"A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode" (USDOE, www.arlevents.com/microgrids2012/briefings/7/0900-steven-bossart.pdf)



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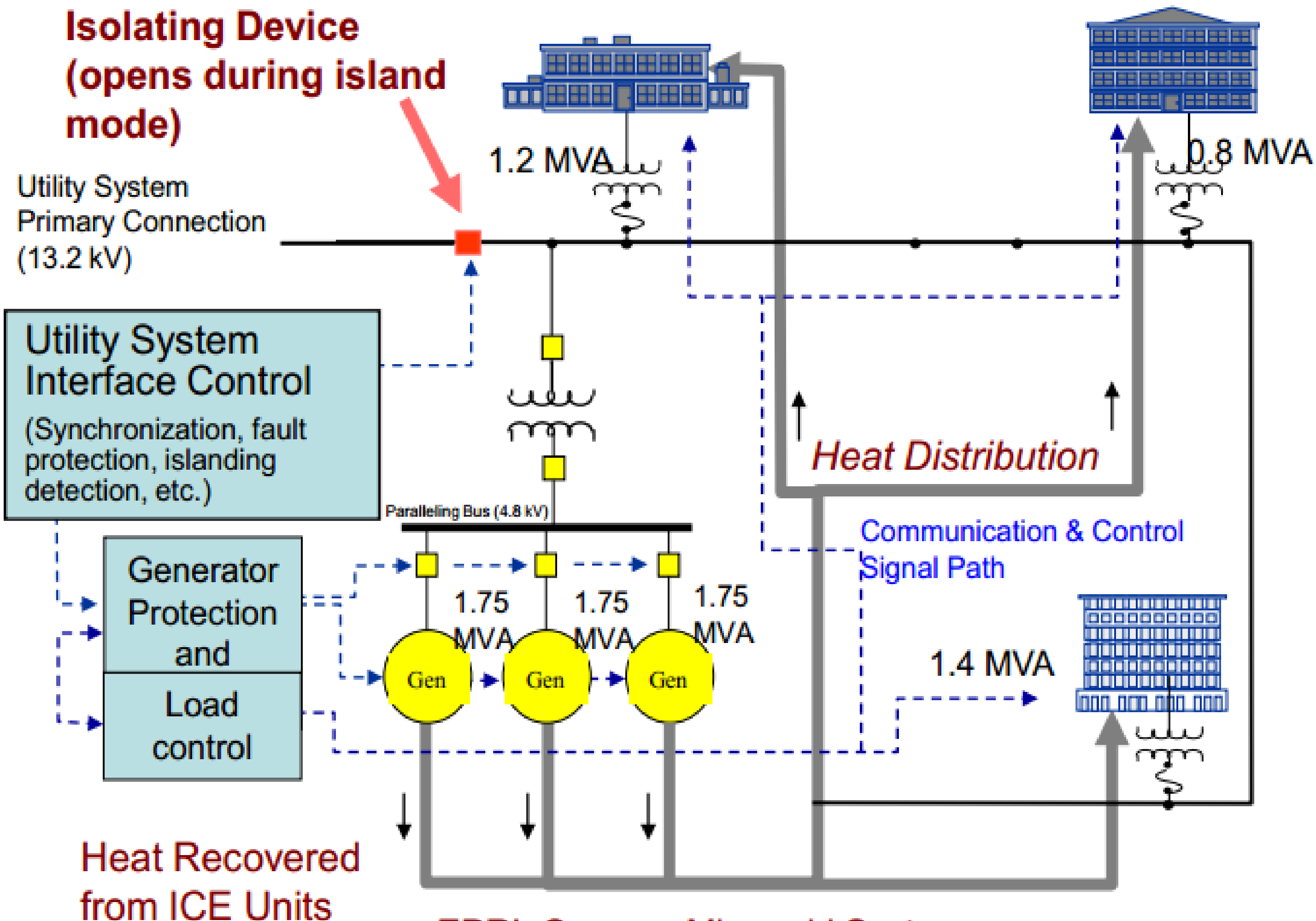
Example: Campus System



EPRI: Campus Microgrid System

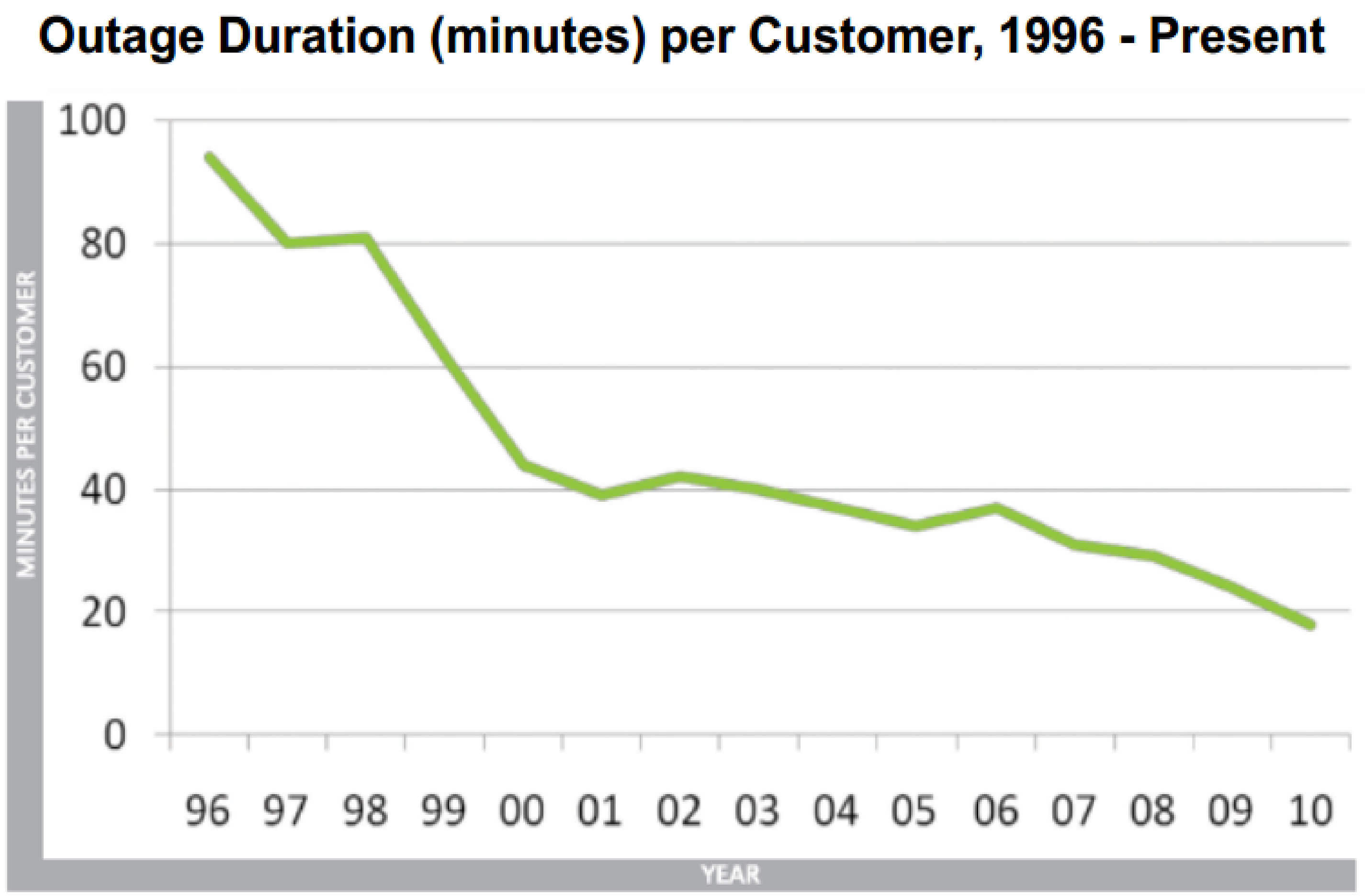
R. Lasseter,, U of Wisconsin, http://energy.gov/sites/prod/files/EAC%20Presentation%20-%20Microgrids%202011%20-%20Lasseter.pdf

90 systems, 2500 MW in US

Potential Benefits of Microgrids

- Improved consumer reliability
- Contribute to grid reliability
- Secure supply against acts of terrorism
- Combined heat & power
- Substitute for distribution investments
- Offset costly retail power ("behind the meter")

Naperville, IL Outage Reductions



www.naperville.il.us/emplibrary/Smart_Grid/NSGI-GalvinCaseStudy.pdf

Note: No generation in this microgrid

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Source: Kay, 2011

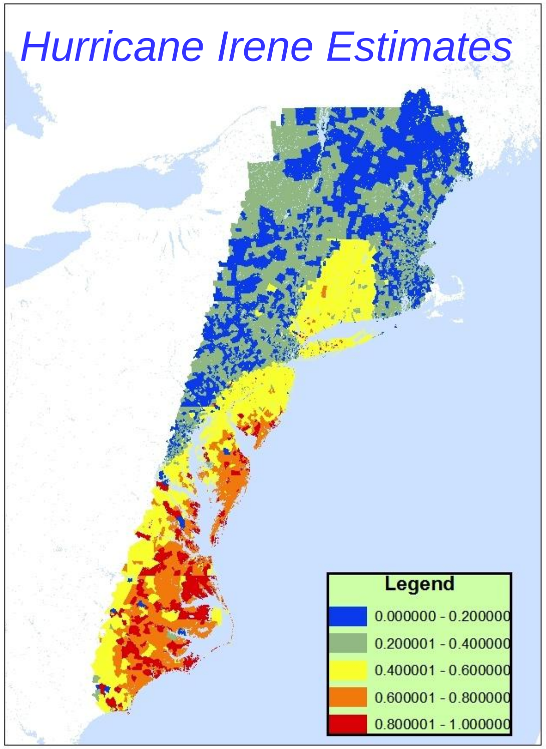
Costs

Energy Resources (30-40%)	Switchgear Protection & Transformers (20%)	Smart Grid Communications & Controls (10-20%)	Site Engineering & Construction (30%)	Operations & Markets
Energy storage; controllable loads; DG; renewable generation; CHP	Switchgear utility interconnection (incl. low-cost switches, interconnection study, protection schemes, and protection studies)	Standards & protocols; Control & protection technologies; Real-time signals (openADR); Local SCADA access; Power electronics (Smart Inverters, DC bus)	A&E (System design and analysis); System integration, testing, & validation	O&M; Market (utility) acceptance

M. Smith, USDOE, http://energy.gov/sites/prod/files/EAC%20Presentation%20-%20OE%20Microgrid%20R%26D%20Initiative%202011%20-%20Smith.pdf

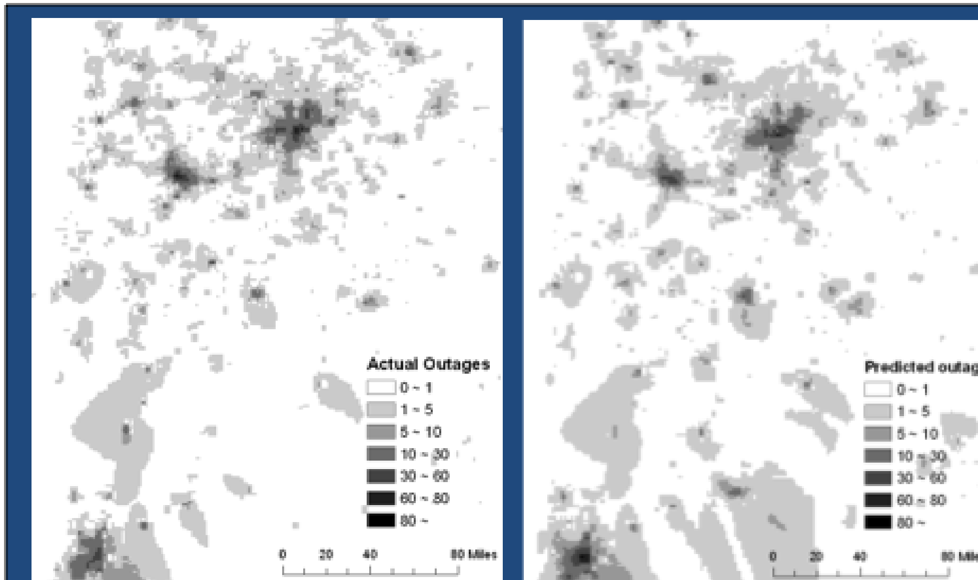
Improved Power Outage Prediction

(Prof. Seth Guikema, Dept. Geography & Environmental Engineering, JHU)



- *Model predicts number of outages in each census tract 2-4 days prior to a hurricane*
- *Average errors <2% for 2-3 day lead time*
- ***Provides a stronger basis for # outside crews to request***
- *Now used by a Gulf Coast utility*

Hurricane Katrina Estimates (Gulf Coast region)



Actual Number of Outages

Predicted Outage Map

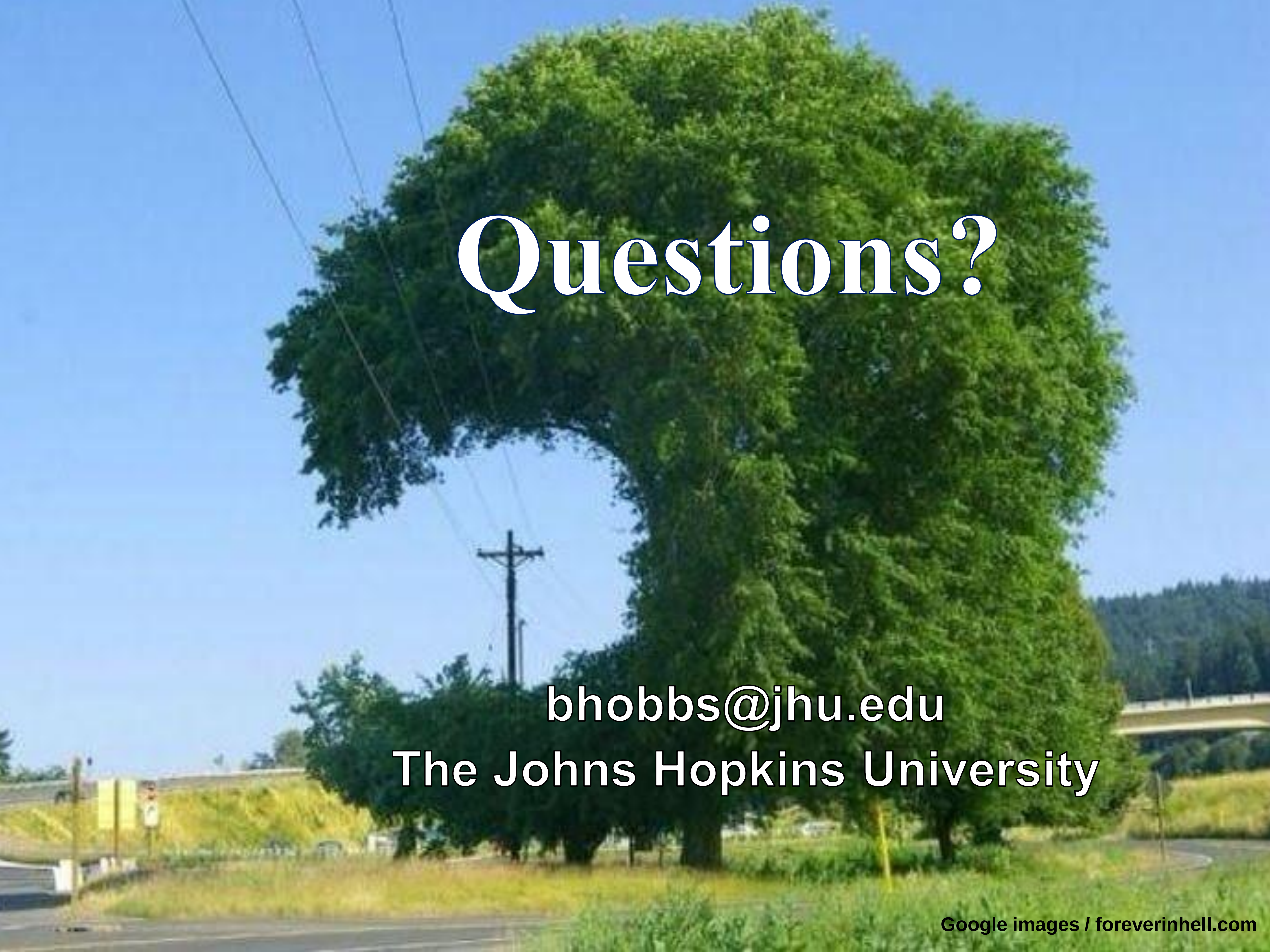
Better predictions
→Better-informed response
→Faster restoration at reasonable cost

Conclusion

- In near-term, microgrid value likely to derive from:
  - Combined heat-power
  - Enhanced customer reliability
  - Energy, voltage support
- Microgrids have low potential to enhance reliability for most Maryland consumers in short-term
- In long-term, microgrids may transform the power system

Recommendations

- EmPower Maryland's cogeneration efforts could be augmented to incent CHP-based microgrids
- Demonstration microgrids at State of Maryland government complexes and universities
- Identify obstacles in Maryland utility law to consumers forming microgrids, sharing power & thermal resources
- Be cautious regarding net-metering/virtual metering/retail wheeling reforms, due to cost-shifting & efficiency effects
  - Microgrids should face marginal prices based on PJM spot prices, and be paid for ancillary services
- Microgrids should not emit more air pollutants than bulk power sources that they displace
  - Require offsets to compensate for their lack of participation in cap-and-trade systems


Questions?
bhobbs@jhu.edu
The Johns Hopkins University
Google images / foreverinhell.com

How Microgrids can Assist Customers in Improving Reliability and Resiliency[1]

Benjamin F. Hobbs

Director, Environment, Energy, Sustainability & Health Institute
Theodore K. Schad and Kay W. Schad Professor of Environmental Management
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The Johns Hopkins University
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Chair, Market Surveillance Committee of the California Independent System Operator

Before the State of Maryland Gubernatorial Task Force on Electricity Reliability
August 28, 2012

Introduction

A microgrid is defined by the U.S. DOE as follows:

> "A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode."[2]

There are other definitions; a looser one, not requiring the controls and ability to island, is commonly used in Europe.

There are on the order of 90 microgrids in operation or planned in the US today, representing 2.5 GW MW of capacity (about 70% of the world's capacity). Generation technologies deployed in microgrids include renewable (PV, wind), fossil-fueled (microturbines, fuel cells, diesel), combined heat & power, and storage (thermal, batteries). In addition, communications, metering, load and generator controls, and interfaces with the grid (protection devices, transformers, solid-state inverters, and controls) are integral parts of microgrids (Figures 1,2).

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[1] Funding by NSF grant "EFRI-RESIN: Development of Complex Systems Theories and Methods for Resilient and Sustainable Electric Power and Communications Infrastructures" is gratefully acknowledged, as is the collaboration of Chiara LoPrete, Anya Castillo, Seth Guikema, and Catherine Norman of JHU, Judy Cardell of Smith College, and Lamine Mili of Virginia Tech. However responsibility for any errors and opinions are mine alone.

[2] S. Bossart, "DOE Perspective on Microgrids", Advanced Microgrid Concepts and Technologies Workshop, Beltsville, MD, June 7, 2012, www.arlevents.com/microgrids2012/briefings/7/0900-steven-bossart.pdf . For general information on microgrids, see www.galvinpower.org/microgrids; www.galvinpower.org/resources/microgrid-hub/microgrid-resources; www.smartgrid.gov; www.sgiclearinghouse.org; www.oe.energy.gov; www.pikeresearch.com/research/smart-grid/microgrids.

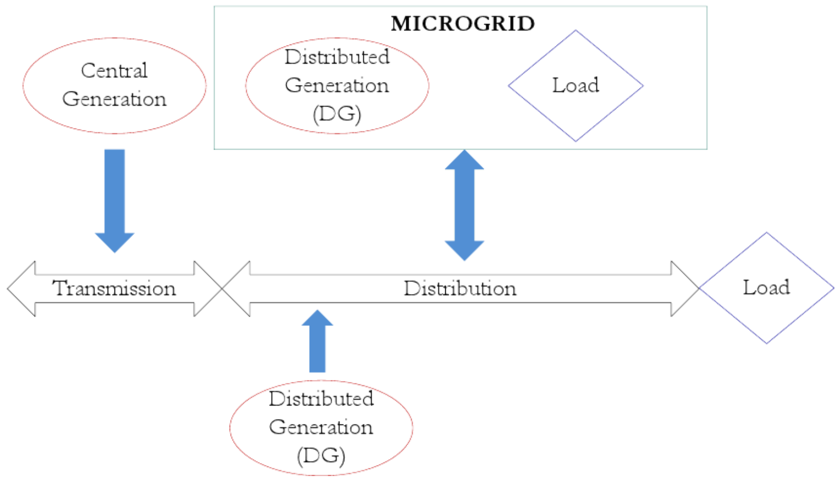

Figure 1. Definition of Microgrids[3]

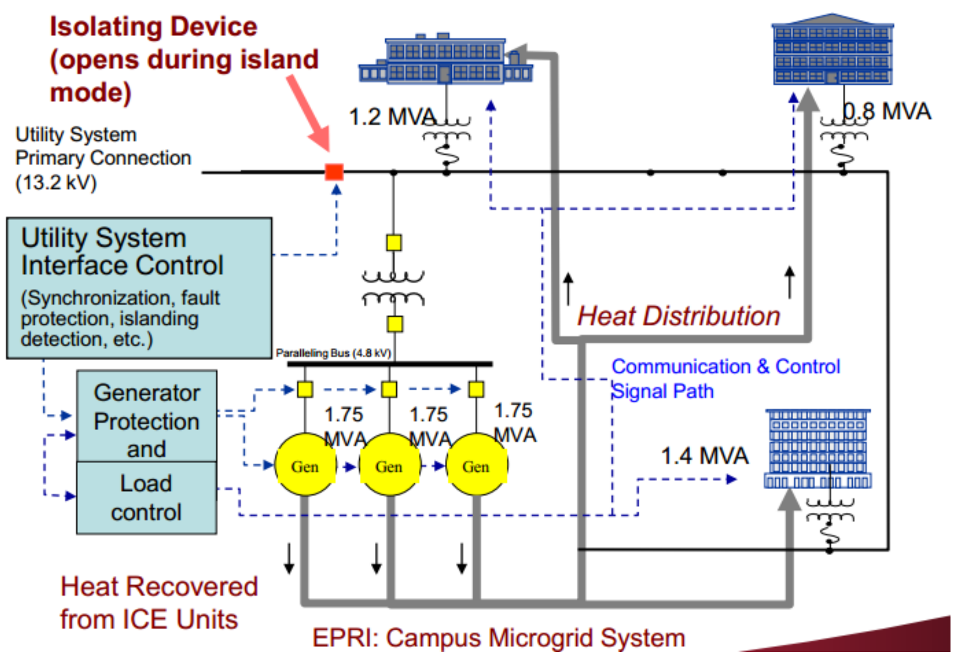

Figure 2. Schematic of Campus Microgrid System[4]

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[3] C. LoPrete, "Essays on microgrids, asymmetric pricing and market power" Dept. of Geography & Environmental Engineering, PhD Dissertation, The Johns Hopkins University, Baltimore, MD 21218, Aug. 2012

[4] R. Lasseter, "Microgrids", U.S. Department of Energy Electricity Advisory Committee, October 20, 2011, http://energy.gov/sites/prod/files/EAC%20Presentation%20-%20Microgrids%202011%20-%20Lasseter.pdf

The Potential Value of Microgrids

Interest is rapidly increasing in microgrid technology.[5] This interest arises from financial and reliability advantages of microgrids.[6]

- **Reliable consumer supply**: by being able to operate in islanded mode, power supply to a microgrid's customers can be maintained despite power interruptions in the bulk power system or distribution network. A greater amount and variety of loads can be served than by the individual emergency generators that are already widely deployed in hospitals and other critical facilities. Advanced microgrids can enhance reliability by also including significant load management and demand response capabilities, and multiple points of electrical coupling with the grid.
- **Enhancement of grid reliability:** advanced load controls in microgrids can, in theory, contribute to improved performance of the regional grid for instance by inter-area oscillations of the transmission system, damping transient angle instabilities after a disturbance, increasing voltage and angle stability margins, and lessening the risk of cascading outages. At Hopkins, we are also investigating how microgrids can increase regional grid resiliency by providing more rapid restoration of power through black start and other services.
- **Security of supply against acts of terrorism:** this is an especially important for military installations and infrastructure control centers.
- **Combined heat & power:** by locating generation near the consumer, waste heat can be used for process and space conditioning purposes. Although my university does not operate a microgrid, Johns Hopkins has made a significant investment in combined heat & power at its Homewood campus, and it has been highly beneficial in terms of power cost savings.
- **Substitution for utility distribution investments:** generation near the consumer can provide reactive power and voltage support services, reduce line losses, and allow the deferral of distribution upgrades.
- **Offsets of costly retail power:** By being "behind the meter", the value of microgrid output might be higher than if the power was sold on the bulk power market. The financial advantage of such "net metering" depends on the relationship of retail and bulk prices. There are legitimate concerns that developments driven by retail rates can result in the shifting of fixed grid and distribution costs to other consumers, and uneconomic development of resources whose cost exceeds their value in the power marketplace.

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[5] Pike Research, Microgrid Deployment Tracker, www.pikeresearch.com/research/microgrid-deployment-tracker-2q12. This capacity is over 50% higher than reported in their fourth quarter 2011 update.

[6] R. Galvin, K. Yeager, and J. Stuller, Perfect Power: How the Microgrid Revolution Will Unleash Cleaner, Greener, and More Abundant Energy, How the Microgrid Revolution Will Unleash Cleaner, Greener, and More Abundant Energy, McGraw Hill, 2008.; R.L. Dohn, "The Business Case for Microgrids. White Paper: The New Face of Energy Modernization," Siemens AB, 2011, http://www.energy.siemens.com/us/pool/us/energy/energy-topics/smart-grid/downloads/The%20business%20case%20for%20microgrids_Siemens%20white%20paper.pdf

- **Power quality:** frequency and wave form can be better controlled for consumers who require higher power quality.

In addition, microgrids are often viewed as a way to promote adoption of sustainable electricity generation technologies. Except for customer reliability, enhancement of grid reliability, and security, many of these benefits can also be provided by distributed generation without the need for the controls and equipment required by microgrids.

Reliability is a primary motivation for microgrids. The Office of Electricity of the U.S. DOE has a 2020 goal of developing commercial scale (< 10 MW) microgrid systems capable of reducing outage time of required loads by >98% at a cost comparable to non-integrated distributed generation solutions, while reducing air emissions by >20% and improving system energy efficiencies by >20%.

There have been reports that existing microgrids have significantly reduced customer outages. Figure 3 is a widely publicized example in which Naperville, IL's municipal utility committed two decades ago to reducing outages and improving efficiency through undergrounding of lines, distribution automation, smart meters, and looped rather than radial distribution. However, Naperville, IL has no generation capacity,[7] so these benefits have been realized from changes to the distribution system and customer metering, not from the ability to island and self-generate.

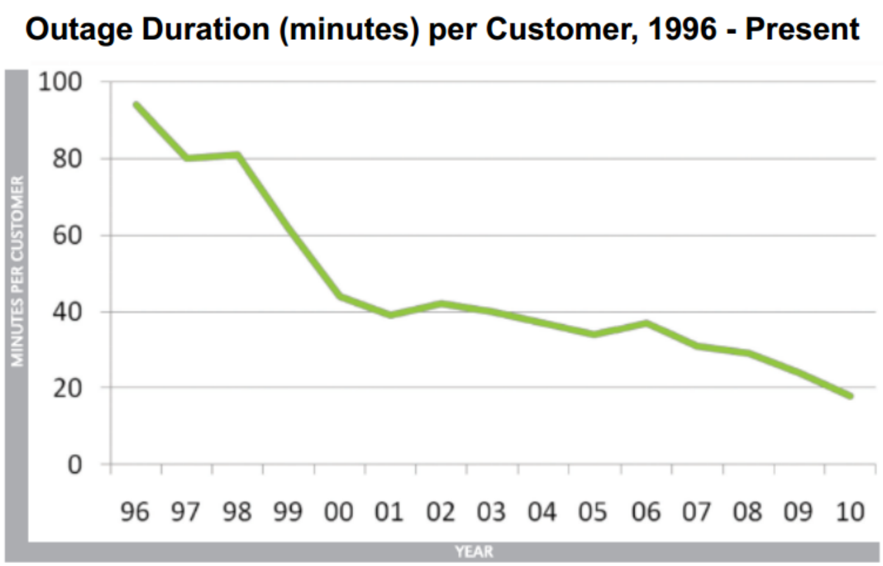

Figure 3. Naperville "Microgrid" Outage History (System Average Interruptible Duration Index)[8]

[7] http://sgstage.nrel.gov/project/city_naperville_ilcity_naperville_smart_grid_initiative/latest_data

[8] J. Kelly, "Microgrids: A Critical Component of U.S. Energy Policy," Galvin Power Initiative, House Select Committee on Energy Independence and Global Warming, May 20, 2010, Washington, DC., www.galvinpower.org/sites/default/files/John_Kelly_Microgrid_Briefing_52010.pdf . See also: www.naperville.il.us/emplibrary/Smart_Grid/NSGI-GalvinCaseStudy.pdf

Enthusiasts for microgrids foresee them transforming the way that we presently generate and use power—at least in the long term.[9] Our analyses at JHU have identified how, in some circumstances, microgrids can lower costs, improve reliability, reduce emissions, and otherwise enhance regional power system sustainability.[10] The U.S. DOE sees the major applications of microgrids that develop over the next decade as including applications to municipalities, military installations, university campuses, commercial parks, and industry.

However, in general, microgrids are a more costly means of serving consumer load than grid-connected power. Table 1 summarizes typical cost components of a microgrid. To justify their expense, the microgrid needs to provide significant additional value to consumers. The major sources of this additional value are enhanced reliability and resilience, and combined heat & power. This limits the economic deployment of microgrids in the next decade to either locations remote from the grid, or areas with high densities of load either willing to pay a premium for more reliable power and the ability to island, or for whom heat for process or space conditioning purposes would have a high value.

Table 1. Major Cost Components of a Microgrid[11]

Energy Resources (30-40%)	**Switchgear Protection & Transformers** (20%)	**Smart Grid Communications & Controls** (10-20%)	**Site Engineering & Construction** (30%)	**Operations & Markets**
Energy storage; controllable loads; DG; renewable generation; CHP	**Switchgear utility interconnection** (incl. low-cost switches, interconnection study, protection schemes, and protection studies)	**Standards & protocols**; **Control & protection technologies**; Real-time signals (openADR); Local SCADA access; Power electronics (**Smart Inverters**, DC bus)	A&E (**System design and analysis**); **System integration, testing, & validation**	O&M; Market (utility) acceptance

[9] Galvin et al., op. cit.

[10] LoPrete, op. cit., Chs. 2 and 3; C. LoPrete, B.F. Hobbs, C. Norman, M. Spakovsky, S. Cano-Andrade, L. Mili, "Sustainability and Reliability Assessment of Microgrids in a Regional Electricity Market", Energy, 41, 2012, pp. 192-202.

[11] M. Smith, US Department of Energy Office of Electricity Delivery and Energy Reliability, OE Microgrid R&D Initiative, Electricity Advisory Committee, October 20, 2011, http://energy.gov/sites/prod/files/EAC%20Presentation%20-%20OE%20Microgrid%20R%26D%20Initiative%202011%20-%20Smith.pdf

Thus, microgrids are too expensive to help the vast majority of Maryland consumers who've lost power to storms in the last few years, at least not for the next decade. Residential customers living in less densely settled areas and who are served by relatively long overhead circuits – precisely those at most risk of storm-induced outages – are the least promising candidates for development of tightly coordinated small generation/combined heat & power microgrid systems.

Nonetheless, over, say, the next two to five decades, it is certainly possible that our power system will be transformed by microturbine, PV, and electric vehicle technology into one in which many homes and perhaps most will have their power, space conditioning, and hot water needs met by in-house generation. Such dramatic changes have occurred in our power delivery systems in the past, and should be anticipated in the future. A grid transformed in this manner could be more economic, sustainable, reliable, and resilient. However, microgrid technology does not promise to have anything more than a niche market in the next 5-10 years, and cannot dramatically change the vulnerability of most of Maryland's consumers to power interruptions in that time frame.

Recommendations

Other sources provide recommendations that are at least partially applicable to Maryland. A report sponsored by NYSERDA identifies several obstacles to microgrid development in New York state, provides a number of recommendations for regulatory and policy reforms and state financing to facilitate microgrid development.[12] The Galvin Electricity Initiative has also offered recommendations along these lines.[13]

My recommendations for Maryland are as follows:

- The State of Maryland's existing efforts to encourage cogeneration (through EmPower Maryland) could be augmented to incent creation of CHP-based microgrids in situations where economic, environmental, and reliability benefits are likely to exceed the costs. Together, the economic benefits of improved energy efficiency from CHP and enhanced reliability could make such microgrids attractive to large commercial and industrial customers.

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[12] M.A. Hymans et al., Microgrids: An Assessment of the Value, Opportunities, and Barriers to Deployment in New York State, Columbia University, Center for Energy, Marine Transportation and Public Policy, Final Report 10-35, Submitted to the NY State Energy Research & Development Administration, Sept. 2010., www.nyserda.ny.gov/~/media/Files/Publications/Research/Electic%20Power%20Delivery/10-35-microgrids.ashx?sc_database=web

[13] Kelly, op. cit.

- State of Maryland government complexes and universities should consider the potential benefits of microgrids as part of their energy management planning. Demonstration projects could help accelerate deployment of microgrids.
- An assessment of utility law in Maryland is desirable to identify potential obstacles to previously unaffiliated consumers forming microgrids and sharing of electricity and thermal resources. If significant, then changes to Maryland rules should be considered.
- I advise caution regarding implementation of net-metering/virtual metering/retail wheeling reforms, since they could result in cost-shifting to other consumers and potentially inefficient distributed generation development relative to grid generation. If the societal reliability and efficiency benefits of a microgrid do justify its cost in a given situation, it should be profitable for its developer and consumer based on participation in bulk markets for power. Retail rates reflecting real-time prices will incent generation at times and places where it is most needed, and should be encouraged. PJM has made provisions for participation of microgrids and other distributed generation in its bulk energy and capacity markets, and microgrids could also provide valuable ancillary services, including reactive power and operating reserves.[14]
- Air pollution emissions from fossil-fuel consuming microgrids should be regulated so they do not produce more emissions than the bulk power sources that they displace, especially considering their proximity to population. In particular, offsets should be required based on estimated emissions to compensate for their lack of participation in cap-and-trade systems for NO_x (under federal law) and CO2 (under RGGI).

[14] See C. LoPrete, op. cit., Ch. 3.

How Microgrids can Improve Reliability and Resiliency: Recommendations

Benjamin F. Hobbs

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Chair, Market Surveillance Committee, California Independent System Operator

Before the State of Maryland Gubernatorial Task Force on Electricity Reliability, August 28, 2012

Short Term Recommendations:

- The State of Maryland's existing efforts to encourage cogeneration (through EmPower Maryland) could be augmented to incent creation of CHP-based microgrids in situations where economic, environmental, and reliability benefits are likely to exceed the costs. Together, improved energy efficiency from CHP and enhanced reliability could make such microgrids attractive to large commercial and industrial customers.
- An assessment of utility law in Maryland is desirable to identify potential obstacles to previously unaffiliated consumers forming microgrids and sharing of electricity and thermal resources. If significant, then changes to Maryland rules should be considered.
- Improved systems for outage forecasting from hurricanes would yield better informed decisions regarding requests for outside crews.

Long Term Recommendations:

- State of Maryland government complexes and universities should consider the potential benefits of microgrids as part of their energy management planning. Demonstration projects could help accelerate deployment of microgrids.
- I advise caution regarding implementation of net-metering/virtual metering/retail wheeling reforms, since they could result in cost-shifting to other consumers and potentially inefficient distributed generation development relative to grid generation. If the societal reliability and efficiency benefits of a microgrid do justify its cost in a given situation, it should be profitable for its developer and consumer based on participation in bulk markets for power. Retail rates reflecting real-time prices will incent generation at times and places where it is most needed, and should be encouraged. PJM has made provisions for participation of microgrids and other distributed generation in its bulk energy and capacity markets, and microgrids could also provide valuable ancillary services, including reactive power and operating reserves.
- Air pollution emissions from fossil-fuel consuming microgrids should be regulated so they do not produce more emissions than the bulk power sources that they displace, especially considering their proximity to population. In particular, offsets should be required based on estimated emissions to compensate for their lack of participation in cap-and-trade systems for NO_x (under federal law) and CO2 (under RGGI).

Maryland Distribution Reliability Roundtable – Customer Investment

Opportunities and Challenges of Microgrid Technology

Dan Ervin, Ph. D.
Professor of Finance
Salisbury University

Summary of Presentation

- Introduction
- Generation Opportunities and Challenges
- Electricity Quality
- Economic Viability
- Ownership Structure
- Safety
- Social Policy

Microgrid Technology

- Local Distribution System
- Local or Distributed Generation
- Storage and/or Backup Generation
- Grid Independence

Generation

- Solar Photo-Voltaic
- Solar Thermal
- Wind
- Natural Gas Turbines
- Small Modular Reactors

Electricity Quality

- Intermittent Generating sources
- Varying Loads
- Small Systems can be less robust

Economic Viability

- Small systems are economically challenged at this time
- Intermittent sources require backup or storage
- Operations and maintenance

Ownership Structure

- Co-op arrangement
- Electric Utility
- Others

Social Policy

- Can microgrids Balkanize the distribution system?
- How will microgrids work in rural areas?
- Will microgrids support social programs like the Electric Universal Service Program?

Conclusions

- Microgrids may change how electricity is delivered to customers
- Microgrids face technical and economic challenges

Executive Order 01.01.2012.15
Improving the Resiliency of Maryland's Electric Distribution System
Summary of Testimony by Dr. Dan Ervin
Opportunities and Challenges of Microgrid Technology

Microgrid technology can be an alternative to the traditional distribution system if properly designed to integrate with the utility grid. Microgrids, with appropriate design and controls, could function as power production and distribution "islands" under some scenarios, providing protection for their users from outages affecting other portions of the electric distribution grid. This approach would be based on small generating units, often referred to as "distributed generation." Although the size characteristics used to define a microgrid can vary, the lower bound is most likely one home or other building that has roof-top solar panels and/or small wind turbines with an appropriate storage system that can provide all or the critical power requirements for a single user. The other end of the continuum is less defined but could be a college campus, business or industrial park, and maybe even a town or city.

A basic microgrid requirement is an electricity generating source. For a variety of reasons, these microgrid generation sources are often renewable in nature. Whatever the source, if it is intermittent, storage or other back-up generation is likely to be essential for the microgrid to operate independently from the traditional grid.

Grid independence, renewable energy and enhanced reliability are exciting prospects; however, whether the microgrid consists of one home or a college campus, several challenges must be met to make the microgrid successful.

The first challenge is developing sufficient generation. The energy density for a solar panel, the most likely renewable source in an urban setting, is approximately 15 – 20 watts per square foot. Therefore, a 10 kW system is approximately 650 square feet. In addition, a solar system is intermittent, requiring storage or another electricity generating source such as back up from the main grid, natural gas turbines, or some other power source.

Turbines and other sources of generation will add expense to the microgrid system and, of course, back up generation from the grid will require compensation as well. Unless the microgrid is always isolated from the main grid, distribution standby charges also will be incurred to prevent other customers from subsidizing the microgrid's intermittent use of the main grid.

Another challenge is electricity quality. To the extent the microgrid serves a varying load, there is the potential for significant changes in electricity quality as large loads cycle on and off. Examples of these kinds of loads are HVAC equipment, water heaters, and refrigerators. These other appliances, and especially electric motors, can exceed the capabilities of solar and even small fossil fuel generators. If the microgrid is to be able to operate independently, these issues must be addressed in the design phase of the microgrid. This can be done through upsizing the generation system or controlling (shedding) load on the microgrid.

Utility-scale grids are large systems with many generating sources serving many different loads. This enormous machine has a great deal of "inertia" and can absorb changes in power demands or disruptions easier than a small system. Conversely, a small fault on a microgrid has the potential to bring all of it down. The control system must be robust to properly manage varying loads and generation in order to prevent damage to either the generator or the load equipment. It must be able to isolate faults, or even swings in load caused by cycling of compressors and other large current drawing equipment, in order to prevent a cascading event.

Some customers, due to preferences for going "green," geographic isolation from the current grid, desire for energy independence, or other reasons may wish to deploy microgrids even if they cost more than other forms of electric service. The State and its electric companies should be prepared to accommodate those interests where possible and in ways that do not require the utility's other customers to subsidize the microgrid.

However, to achieve widespread deployment, these systems must be economically viable. Currently, and in general, they do not appear to meet this criterion. The renewable generating sources face major hurdles themselves, in part because they currently cost more than other generation. Additionally, because of their intermittent characteristics, they require storage or another stand-by generating source. Moreover, while some portions of today's distribution systems can handle bi-directional electricity flow, they were not designed for it. Therefore, in some areas the grid will need updating to accommodate this new use, and additional costs will be incurred.

Questions also arise as to the ownership structure of the grid and distributed generation portions of the microgrid. Unless starting from scratch in a discrete geographic area, the utility is likely to own the distribution grid portion. As to the distributed generation assets, either the utility or the microgrid customers, or an entity chosen by those customers, could own them. There are pluses and minuses to each.

Along with the ownership questions are a host of operating and maintenance concerns. Of particular importance, the owner must address safety and liability issues. It is a challenge to completely disconnect from the existing grid and this must happen to protect anyone working on a line thought to be de-energized. Interconnected microgrid systems must be completely and instantly off when utility service is off or when utility and other emergency personnel are in contact with lines; therefore, a microgrid must have a method and the controls to completely disconnect from the system in order to operate as an island.

Finally, microgrids can affect social policies. Taken to the limit, microgrids could lead to the "Balkanization" of the distribution system. How would microgrids work in rural areas? How will low income programs survive? If wealthier customers form microgrids, what does that mean for other customers? For better or worse, public utilities have been tasked with addressing a variety of social topics and, at some level of microgrid deployment, their ability to do so may be compromised.

Microgrids hold the promise to change the public utility landscape. In order for this to occur in a way that provides net benefits to society, many issues must be evaluated and addressed. The criteria for this evaluation will have reliability, cost, environmental and societal components.

Executive Order 01.01.2012.15
Improving the Resiliency of Maryland's Electric Distribution System
Recommendations for Improving Maryland's Electric Distribution System
Prepared by Dan Ervin

Short-Term Recommendations

1. Power inverters and small electricity generators can provide short-term, limited back-up power.

   Power inverters connect to automobile batteries and can power small electric appliances and equipment. Small inverters connect through a cars lighter plug while larger ones must be connected directly to the battery. The battery can quickly drain requiring periodic charging by running the car engine.

   Small generators, typically fueled by gasoline, can power larger appliances such as refrigerators. This could be an important option for preserving food during extended outages

2. Smart grid technology may be critical to quick and responsive electricity service restoration. This technology can facilitate system recovery effort by remotely identifying high priory issues. Smart grid systems require adequate funding to reach their full potential.

3. Continue to support infrastructure maintenance and development including vegetation abetment programs. Maryland can enhance reliability by assuring infrastructure maintenance is properly funded.

Long-Term Recommendations

1. Hardening the distribution systems where the benefits are greater than the costs will increase reliability. There is evidence that placing distribution systems underground does not significantly improve reliability and can complicate power restoration, therefore a mandate to bury the systems may not be optimal.

2. Consider re-integrating electric utilities. Currently, approximately 30 percent of Maryland's electricity is provided by out-of-state entities. The Eastern Shore of Maryland imports about 70 percent or more of its electricity. There is not a single major generating unit on Maryland's Eastern Shore. Transmission congestion increases as Maryland imports this quantity of electricity. This is especially true at PJM's eastern interconnect. Perhaps reliability would increase if more generating units are built in Maryland

3. Cyber-security in a smart grid environment is a concern and requires examination.

Honeywell

Micro-Grid Definition

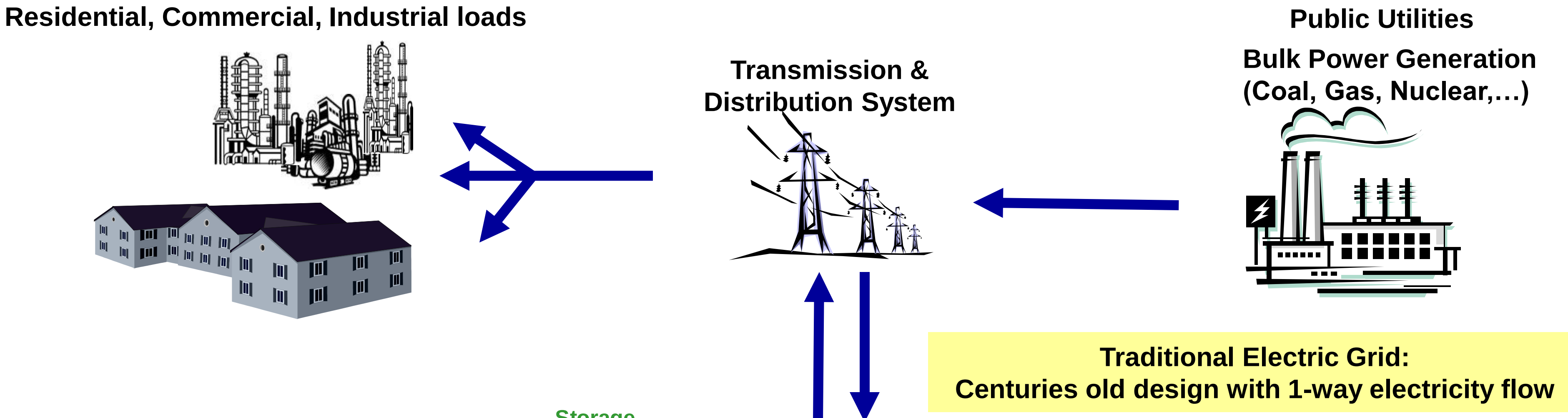
"Intelligent management of local (electric) power generation supplying local (electric) loads"

- Can operate totally independent of a utility grid (isolated)
- Can interface with a utility grid and have islanding capability

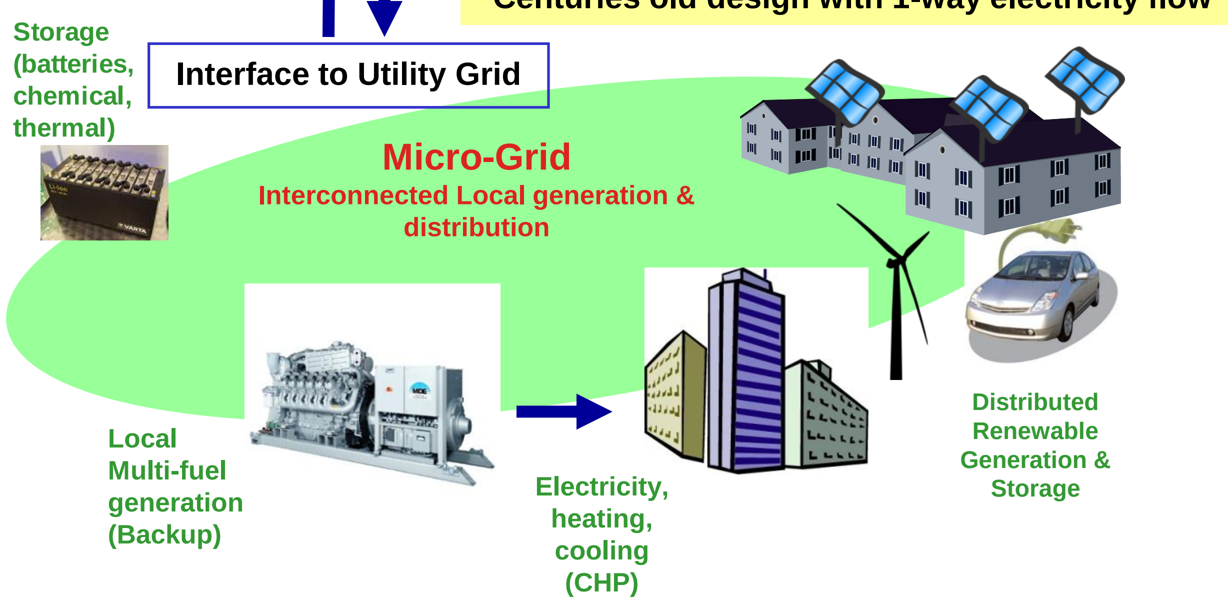
Customers who primarily need to interface with a utility grid and have islanding capabilities to support critical functions when necessary:

- *University Campuses*
- *Fixed Military Installations/Bases*
- *Commercial Building Complexes (e.g., Industrial parks, corporate headquarters)*
- *Data Centers*
- *Hospitals*
- *Communities with a utility infrastructure, but experience power shortages*

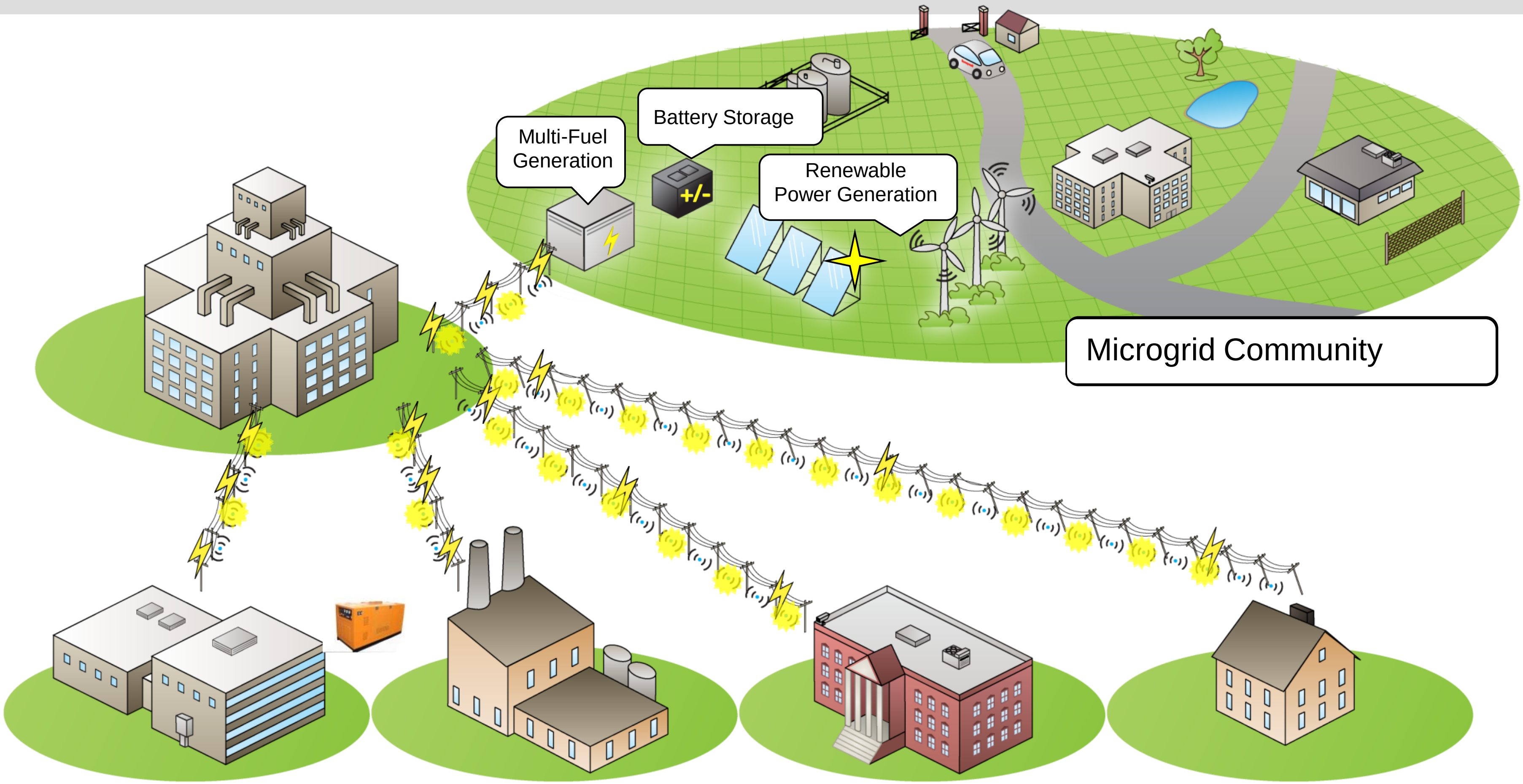
Micro-Grids: Modernizing Electric Power Grid



- **Micro-Grid Benefits**
  - **Energy security**
  - **Increased reliability**
  - **Improved efficiency**



MicroGrid Vision



Microgrids enable energy security and reliability needed to keep and attract large employers

Recommendations

- Short-Term
  - Educate relevant constituency (target verticals) about what exactly a microgrid is, and where it can be cost-effectively implemented to help a customer meet their energy goals as part of an integrated solution that includes energy efficiency and demand management.
  - Work with utilities to identify parts of their utility grid that are problematic in regards to reliability and identify potential customers who could implement microgrids that would have technical and financial feasibility.
  - Identify other solutions (such as standby generation) that are not truly microgrids, but that help improve energy security and can be implemented where microgrids are not technically or financially feasible.
- Long-Term
  - Direct the utilities to undertake a thorough investigation of microgrids as a cost-effective means to improve energy reliability as part of the integrated solution and consider incentive programs that speed their adoption.
  - Ensure that utility interconnection requirements continue to place safety of employees, external and host customers as paramount, using methods that are as cost effective and timely as possible.
  - Continue to publicize public benefits of microgrid installations.

Federal Research Center at White Oak, MD

What was Needed

- Energy Infrastructure Master Planning
- Establishment of Microgrid
- Critical Load Redundancy/ Firm Capacity
- Demand Response Capability
- Energy VE of Building Designs
- Phased Energy Infrastructure Development
- Adaptive Reuse of Historic Building
- Support to Building LEED Certification

About the Project

The Food and Drug Administration (FDA) and the General Services Administration (GSA) are working together to consolidate FDA operations at the government owned White Oak site in Montgomery County, Maryland. A series of ESPC projects were used to accelerate the timeline for the move, reduce the costs associated with the mechanical systems in the new buildings, and provide a reliable and efficient energy infrastructure to support the White Oak campus.

Energy & Environmental Benefits

Annual Energy Savings:

- 640,000 MBtu (Current)

Pollution Prevention (annual):

- 50,000 metric tons CO2-equivalent (Current)

THANK YOU!

Tom Glennon
Director of Engineering– Honeywell Building Solutions
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Tom Glennon - Director of Engineering

Tom Glennon is the Director of Engineering for Honeywell Building Solutions, Americas. In this role since June 2010, Tom is responsible for integrating technologies, people, processes and tools to support a broad range of customer solutions for energy efficiency and sustainability. Previously, he has led international engineering teams in the design/manufacturing sector.

Tom received his BS in Electrical Engineering from the Illinois Institute of Technology.

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